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THERMAL ANALYSIS OF A "TANDEM" COMPOUND ENGINE.

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In a recent paper, "On the Economics of 'Automatic' Engines," the writer developed at considerable length the principles involved in the study of the thermal distribution in such engines. He illustrated his methods by the computation, from data found by earlier experiments, now familiar to all interested in the subject, and known to be sensibly accurate, of the quantities of heat and power utilized and wasted under specified conditions of operation, such as are usual with this class of machines, giving a tabulated statement of the amount of heat-energy supplied, the quantity utilized by conversion into dynamic energy, that wasted as heat by conduction and radiation, and that lost by internal transfer without transformation and by

other than thermo-dynamic and necessary waste.* In the present paper, the writer proposes to show what is this distribution in an engine of familiar and representative type in good standing among machines of its class, as determined by a careful and fairly complete trial, made by the methods which the writer has been accustomed to employ and including the system of comparative analysis based upon the original work of Hirn and of Dwelshauvers-Dery, such as must always be employed when seeking to ascertain the nature and extent of those losses and wastes which distinguish the ideal and real engines.†

As remarked in the paper above referred to:

"The exact expenditure of heat, steam and fuel under specified representative conditions of this case, including steam-pressure, back-pressure, ratio of expansion, and boiler-efficiencies, can be computed for the thermo-dynamic, ideal, case; and, knowing the magnitude and conditions of physical operation of the engine, friction included, its wastes of energy, whether thermal or dynamic, can be very closely obtained by computation, and these wastes being added to the total thermo-dynamic expenditure, the gross outlay of energy becomes known and the economical problem can be solved." The following was given in illustration of these methods as determined for an "automatic" simple, condensing, engine, rated at ten to fifteen horse-power; having a cylinder six inches in diameter and eight inches stroke of piston, a speed of 280 revolutions a minute, and proportioned for a steam-pressure of 100 pounds. Compression was assumed complete and leakage insensible.

The demand for heat and steam was computed on the assumption of the data given below; the conditions as to waste being illustrated in the Sandy Hook experiments of 1884.‡ External wastes were assumed to average 0·5 B. T. U. per square foot of exposed surface, and per degree range of temperature from atmospheric—here taken as 100°

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* *Jour. Franklin Inst.*, Oct. 1892.

† *Manual of the Steam Engine*, part i, chaps. v, vi.

‡ *Ibid.*, chap. v, § 129, p. 501.

F. Internal wastes were taken as a fraction of the total steam supplied,

$$w = a / d \cdot \sqrt{r\, n}$$

where the coëfficient $a = 4$ in the case assumed to be fairly represented of that here considered: d is the diameter of cylinder in inches, r the ratio of expansion, and n the number of revolutions per *second*. Friction wastes were taken as giving an efficiency of engine of 0·85.* J is taken as 778. The following are the data:

DATA.

$p_1 =$	75	95	115	135	155′
$p_3 =$	5	5	5	5	5
$r =$	1·6	2	4	8	16
$c = \frac{1}{r} =$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{1}{16}$

Pressures were measured from absolute zero.

The thermo-dynamic effect of the steam was computed by the equations of Rankine.†

The results of those computations are presented, in part, in the accompanying table.

These computations for the ideal case show the consumption of steam under the specified conditions of pressure and cut-off to vary from a minimum of about eleven pounds per horse-power and per hour, at 155 pounds absolute pressure, to fifteen and one-third at the best cut-off for seventy-five pounds. But the introduction of the wastes produced an entirely different showing, and, for this case, the minima were found at expansions approximating

$$r = 0{\cdot}5 \sqrt{p}$$

or from one-seventh at 155 pounds to one-fourth, nearly, at

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* *Manual of the Steam Engine*, part i, chap. v, § 132–134.

† *Rankine's Prime Movers; Thurston's Manual*, p. 398; and chap. v, § 137.

seventy-five pounds above a vacuum, initial pressure in the cylinder; while the steam consumption became about

$$w = 250 \div \sqrt{p}$$

ranging from twenty-three to twenty-eight pounds per indicated horse-power per hour, and twenty-seven to thirty-three pounds per dynamometric horse-power. These figures are not large for the size and kind of engine taken in illustration of the method intended to be exhibited in the paper quoted; but they may be taken as representative of those to be expected with ordinarily good practice. With larger, faster, or better designed, and especially better protected engines, wastes may be reduced somewhat below those stated above and correspondingly nearer approximations effected to the goal sought by the engineer in designing economical engines—*i. e.*, to the performance of the ideal machine.*

In the case here to be presented, the engine is a compound, is much larger and more powerful, and affords better opportunity to effect this approximation. Its dimensions are:

DIMENSIONS OF ENGINE.

Diameter of high-pressure cylinder, . .	12	inches.
Diameter of low-pressure cylinder, . . .	20	inches.
Length of stroke (nominal), ...	14	inches.
Length of stroke (measured), ...	13·97	inches.
Length of stroke (measured), ...	1·164	feet.
Diameter of piston rod, ...	1·9375	inches.
Area of high-pressure piston, head, . . .	113·098	square inches.
Area of high-pressure piston, crank, . .	110·149	square inches.
Area of low-pressure piston, head, . . .	311·211	square inches.
Area of low-pressure piston, crank, . . .	311·211	square inches.
Piston displacement, high-pressure, head,	·91425	cubic foot.
Piston displacement, high-pressure, crank,	·89042	cubic foot.
Piston displacement, low-pressure, head,	2·51575	cubic feet.
Piston displacement, low-pressure, crank,	2·51575	cubic feet.
Clearance, high-pressure cylinder, head,	·15716	cubic foot.
Clearance, high-pressure cylinder, crank,	·14718	cubic foot.
Clearance, low-pressure cylinder, head,	·31422	cubic foot.
Clearance, low-pressure cylinder, crank,	·31925	cubic foot.

* *Rankine's Prime Movers; Thurston's Manual*, p. 398; and chap. v, §§ 129–131.

Clearance, per cent. of stroke, high-pressure cylinder, head,	17·50
Clearance, per cent. of stroke, high-pressure cylinder, crank,	16·20
Clearance, per cent. of stroke, low-pressure cylinder, head,	7·40
Clearance, per cent. of stroke, low-pressure cylinder, crank,	7·60
Volume of receiver-space,	1·1455 cubic feet.
Volume of space in pressure-plate,	·12819 cubic foot.
Volume of space in pressure plate, per cent. of stroke,	5·09

The design and arrangement of the engine is shown well in the plate exhibiting the method of fitting up for trial, and need not be here described.* It was built by the inventor, Mr. A. L. Ide, and is a "tandem compound" of the style known to the trade as "the Ideal." The computations of probable wastes, on the assumed basis previously taken, of correspondence with those of the Sandy Hook experiments, would give figures, reduced to expenditures per horse-power and per hour, about one-half those of the smaller engine above referred to, with its six-inch cylinder.† and would, on that basis and with ten per cent. friction, be as follows:

At the lowest pressure, 75 pounds, with the engine alluded to, maximum economy of steam and fuel was found at a cut-off very near $\frac{7}{32}$, or a ratio of expansion of about 4·5, when the dynamometric power was taken, or at about a cut-off of 0·2 and $r = 5$, on the basis of indicated power. These figures became about 3·16 and 5 at 95 pounds, $\frac{11}{64}$ and 6 at 115, $\frac{5}{32}$ and 6·4 at 135, and $\frac{9}{64}$ and 7 when the pressure was 155 absolute, or 140 pounds by gauge. (See *J. F. Inst.*, Oct., 1892.)

The minimum cost of power, in steam consumed, remains not far from the cut-offs identified for the first representative case; but the computed weights demanded are reduced very considerably by the fact that the wastes are but about

* For details of method, see *Thurston's Engine and Boiler Trials*, or *Carpenter's Experimental Engineering*.

† See *Manual*, chaps. v, vi.

EXTRA-THERMO-DYNAMIC WASTES.

*Total Consumption of Steam.**

p_1	Cut-off.	Pressure, Pounds per Sq. In.	Steam per I.H.P. per Hour (Ideal) W.	Total Waste, Pounds per I.H.P. and per Hour.	Total Consumption, Pounds per I.H.P. and per Hour.	Same per D.H.P. Machine Eff., 0·90.
16	1–16	75	15·85	11·5	27·35	30·6
8	1/8	75	15·32	7·5	22·82	25·4
4	1/4	75	16·72	5·5	22·22	26·7
2·7	3/8	75	18·48	5·3	23·78	26·4
2	1/2	75	21·44	5·3	26·74	29·7
1·6	5/8	75	24·76	5·2	29·96	33·3
16	1–16	95	13·74	8·7	21·44	23·8
8	1/8	95	13·21	6·2	19·41	21·6
4	1/4	95	15·42	4·8	20·26	22·5
2·7	3/8	95	17·72	4·7	22·42	22·7
2	1/2	95	20·34	4·8	24·14	27·0
1·6	5/8	95	23·11	4·6	27·71	30·8
15	1–16	115	11·91	8·0	19·91	22·1
8	1/8	115	12·58	5·2	17·78	20·6
4	1/4	115	14·97	4·8	19·77	22·0
2·7	3/8	115	17·35	4·6	21·95	24·4
2	1/2	115	19·88	4·5	24·38	27·1
1·6	5/8	115	22·60	4·0	26·60	29·9
16	1–16	135	11·38	7·5	18·88	21·0
8	1/8	135	12·32	5·6	17·92	19·9
4	1/4	135	14·67	4·7	19·37	21·5
2·7	3/8	135	16·96	4·4	21·36	23·7
2	1/2	135	19·54	4·4	23·94	26·5
1·6	5/8	135	22·25	4·4	26·65	29·6
16	1–16	155	10·98	7·1	18·08	20·1
8	1/8	155	12·05	5·5	17·55	19·5
4	1/4	155	14·41	4·6	19·01	21·0
2·7	3/8	135	16·72	4·4	21·12	21·1
2	1/2	155	19·38	4·3	23·58	25·1
1·6	5/8	155	21·95	4·1	26·05	28·9

* The mean effective pressure here found is as before, not far from

$$p_2 = 6\sqrt{p_1}$$

and the pressure to be adopted by the designer for such cases will be greater, perhaps not far from

$$p_1 = 5\sqrt{p_1}$$

gauge-pressures being taken; while the power of the engine is, for the best cases,

$$I.\ H.\ P. = 0{\cdot}025\ d^2\sqrt{p_1},\ \text{nearly},$$

slowly rising with increasing pressure; d being here the diameter of the large cylinder,

$$D.\ H.\ P. = 0{\cdot}022\ d^2\sqrt{p_1},\ \text{nearly}.$$

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one-half those previously found for the smaller engine. These wastes averaged eight or nine pounds for the latter, and are about four and one-half for the former. It will be interesting to now compare these computed results with the actual performance of the machine. A single trial will suffice, as it will establish the constants for the engine, and the behavior of the machine for other conditions than those of the trial may be then computed with satisfactory approximation, as required or desired.

The whole work of preparation and management of the trial was undertaken by Mr. F. P. Ide, one of the computers of the data given by the writer for the cases above described, and the methods employed were those customarily carried out in regular work in the Sibley College laboratories, where similar purposes are in view. It is here presented somewhat fully, both as illustrating those methods and as giving interesting data from this just now peculiarly interesting class of machine, the "high-speed engine" adopted so generally in the distribution of electrical energy. The details of the machine need not be here given, as they are foreign to the purposes of this paper.* It is only necessary here to say that the machine is carefully balanced, has good provisions for free lubrication, and, in the only case in which the writer has had extended experience with it,† has shown itself an excellent example of its class.

The arrangements of the apparatus will be seen by reference to the engraving.

The load was furnished by *two* "Prony" brakes. The brake-wheels were cast with flanged edges, so that water might run upon the inside of the pulleys. A one-inch pipe carried water to the wheel, while a one and one-half inch pipe carried it away. The supply pipe was reduced to about

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* For details, see *Manual of the Steam Engine*, part i, art. 35, p. 142.

† An engine of this kind was built in the shops of Sibley College, Cornell University, and has now for several years, done good work, driving dynamos for experimental work in the Department of Physics. The trial to be here described was the first complete investigation of its kind made with the type of engine in question, and had peculiar interest for the writer and for the builder of the engine for this reason.

one-half inch at the end, to act as a nozzle and throw the water into the wheel at the velocity given its rim, so as to avoid splash.

These wheels were 6 feet in diameter, and of 14-inch face.

The quantity of heat to be removed was approximately known, and accepting the constants given by Box, we have as the amount which may be conducted through the rim, for the surface, eleven square feet, and a thickness of two inches:

$$\begin{aligned} U &= (233 \times 11 \times 100) \div (2 \times 60) \\ &= 2136 \\ &= 1{,}661{,}808 \text{ (foot-pounds per minute)} \\ &= 50{\cdot}3 \text{ horse-power.} \end{aligned}$$

It was found, however, that double this power could easily be absorbed. It is probable that nearly one-half the heat generated was dissipated by contact with the air, and by radiation, permitting the brake to easily absorb 100 horse-power.

A surface condenser was used, rated at sixty horse-power. It had 150 feet of cooling surface. To free the condenser a power pump, with 5-inch cylinder and 5-inch stroke, was employed. It was belted to an 18-inch pulley on the engine shaft. The speed was one-third that of the engine. It was of ample size, and performed its work well.

The discharge water was weighed in tanks, and the supply to the condenser was at the same time metered, the tanks serving to calibrate the meter at short intervals. Thermometers were introduced at every important point and frequent readings taken. The indicators were standardized instruments and the motion was conveyed by wire, to avoid all measurable stretch. A counter was secured on the engine frame and driven from the valve-rod. A pencil attached to the valve-rod permitted exact measurements of the motion of the valve to be obtained, and their relation to the motion of the piston noted.

The quality of the steam entering the engine was determined by a calorimeter, and the quality of that entering the low-pressure engine was similarly ascertained. This

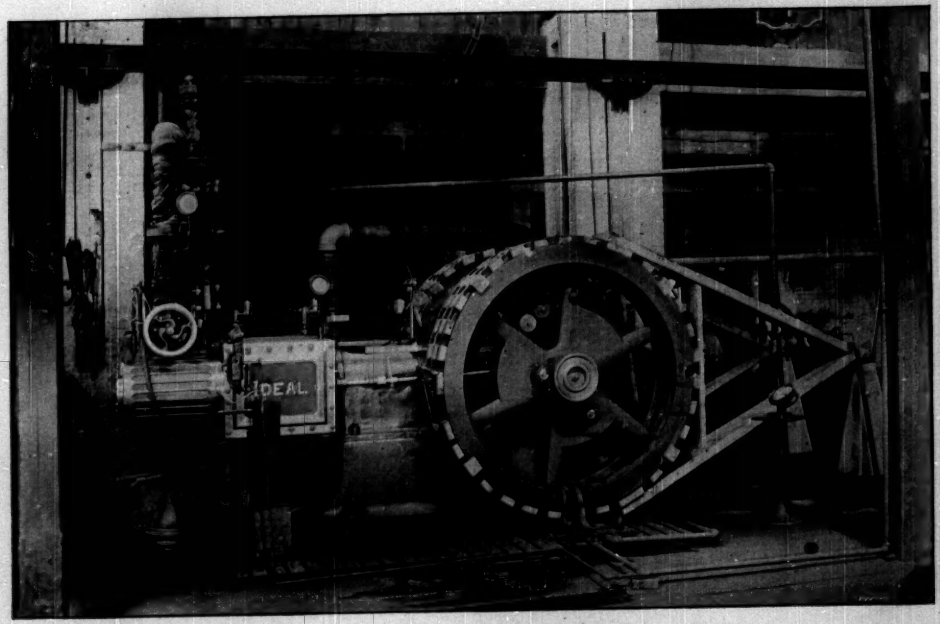

FIG. 1—Engine ready for trial.

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was continuous in its operation. The barometric pressure was measured by a mercurial barometer, and that in the condenser was determined in the same manner. In the work of testing, some difficulty was experienced in securing a water supply from the city mains for the condenser, and this restricted the formation of a good vacuum; otherwise the conditions were usually all that could be desired. The computations are given for the best set of data obtained after trial runs had shown what could be accomplished under the circumstances. The work was done at night to insure freedom from interference with the operations of the trial after the conditions of the test were once established. The following are the results:

DATA AND RESULTS.

Time of starting,	6.45 P. M.
Time of stopping,	11.45 P. M.
Duration of trial,	5 hours.
Total number of revolutions (per continuous counter),	60,300
Revolutions per minute,	201
Barometer in inches of mercury,	29·40
Atmospheric pressure,	14·50 pounds.
Boiling temperature at atmospheric pressure,	211°·10
Boiler pressure by gauge,	98·00 pounds.
Boiler pressure, absolute,	112·50 pounds.
Pressure in steam chest, low-pressure cylinder,	34·00 pounds.
Vacuum gauge, inches of mercury,	22·99
Temperature of condensed steam,	130°·8
Temperature of injection water,	47°·9
Temperature of discharge water,	106°·7
Temperature in calorimeter, steam pipe,	212°·8
Quality of steam in steam pipe,	95·50 per cent.
Quality of steam in compression (assumed),	100·00 per cent.
Quality of steam in exhaust,	93·30 per cent.
Total weight of condensed steam,	11594·50 pounds.
Pounds of wet steam per stroke, mean,	·09614 84
Pounds of wet steam per stroke, head,	·103593
Pounds of wet steam per stroke, crank,	·088704
Cubic feet of condensing water per minute (by meter),	9·304
Pounds per revolution,	3·033
Pounds per stroke, head,	1·634
Pounds per stroke, crank,	1·399

Length of brake arm,	8·07	feet.
Gross weight on brake scale,	367·	pounds.
Net weight on brake scale,	323·75	pounds.
Available delivered horse-power,	99·99	

The brake could not measure all power delivered from the engine, as the engine drove the air-pump arrangement; and this was separately measured by employing an electric motor, when it was found that the power absorbed by the pump was 0·7 horse-power, and, with its accessories when at work, 1·18 horse-power, giving as a total D.H.P 101·17 horse-power, and a machine-efficiency, for the engine itself, of 90·16 per cent. The engine was new and had not been smoothed up by work.

The indicator cards were measured by planimeter. The following are the average mean effective pressures and corresponding power:

	Head.	*Crank.*	*Total.*
M.E.P., high-pressure cylinder,	30·096	26·460	—
M.E.P., low-pressure cylinder,	16·854	13·729	30·579
I.H.P., high-pressure cylinder,	24·132	20·664	44·796
I.H.P., low-pressure cylinder,	37·188	30·294	67 482

Total I.H.P.,	112·28	
Total D.H.P.,	101·17	
Efficiency per cent.,	90·16	

Total weight of wet steam,	11595 50	pounds.
Weight of wet steam per hour,	2319·10	pounds.
Weight of dry steam per hour,	2234·72	pounds.

Weight of steam per I.H.P. per hour,	*19·903*	pounds.
Weight of steam per D.H.P. per hour,	*22·35*	pounds.

The indicator diagrams were found to be sufficiently well taken and finely drawn to permit the application to the case of the methods of Hirn and Dwelshauvers-Dery; the quantity and quality of the steam at every instant in the cylinder being determinable, and the measures of heat transformed and heat transferred without transformation being readily obtained by comparison with the data secured from the observations of boiler performance and steam-supply. Hirn's principle, as here applied, reads thus: "Between any two positions of the piston, the quantity of

heat, which has done external work, and that which is exchanged between the metal and the steam, form a sum equal to the difference between the amount of heat in the steam in those positions; increased (if necessary) by the heat that may have been introduced with new steam, or diminished by that which may have left the cylinder."

The quantity and quality of the steam entering the engine from its steam pipe being measured, and the quality of the mixture discharged from the machine into its condenser being similarly determined, the progressive variations of quality of the charge from the one to the other of its limits of operation within the engine become easy to trace by exact measurement of the pressures and volumes of the steam shown on the diagram. It is known from the data relating to the entering steam what volume and pressure should be exhibited throughout its course through the engine, and the loss of pressure or of volume, at any given instant, as exhibited by the examination of the indicator diagram, gives the measure of loss due to condensation by abstraction of heat from any cause whatever. The condenser supplied data which check any errors in the comparatively difficult measurements of the indicator diagram, and gives comparatively accurate measures, also, of the weight of fluid entering the machine and should give results precisely corresponding with the determinations of weight of feed-water made at the boiler and of quality of the steam entering the steam chest of the engine. The quantity of the fluid leaving the engine at exhaust and entering the condenser is evidently the difference between the quantities of fluid entering the latter as the cooling fluid and that leaving it through the hot-well.

The losses of heat result in the condensation of steam in such quantity as may be required to supply that heat from its stock of "latent" heat or stored energy, in potential form, and correspondingly reduced volume of working fluid. These losses consist of*

* *Manual*, chap. v.

(1) Heat transformed into work by thermo-dynamic action.

(2) Heat wasted by the unavoidable thermo-dynamic loss at the end of expansion.

(3) Heat lost by conduction and radiation from the exterior of the cylinders and passages.

(4) Heat wasted by absorption into the metal of the cylinder, and, later, returned to the steam and rejected with it into the condenser without doing useful work.

The compound engine has the advantage of reducing this last waste; while it exaggerates the third of the series. It reduces the last, however, so greatly as more than to compensate the exaggerated loss by external conduction and radiation—provided it is properly proportioned—and permits, thus, the adoption, economically, of a larger ratio of expansion and the securing of higher efficiency than would otherwise be practicable, by the reduction of the second form of waste above enumerated, with consequent increase of the proportion usefully transformed under the first head of our category. In "receiver engines," wastes by conduction and radiation from the intermediate receivers, as well as from the added cylinders, tend to reduce the gain from restriction of internal wastes.* The application of the Hirn system of study to this case involves the determination of the condition of the working fluid as it traverses these receivers and the intermediate steam-passages, as well as at entrance into the high-pressure cylinder and at exit into the condenser. A steam-gauge and a calorimeter provide the means of obtaining the desired data at each of these points. It still remains uncertain, usually, just in what proportion the water carried by the steam is shared between the two ends of the cylinder; and it must generally be assumed that it is divided between them in proportion to steam taken by each.

The data obtained, in the present case, from the trial here referred to, are as follows:

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* *Manual*, chap. vi.

HIRN'S ANALYSIS—DATA.

High-pressure Cylinder.

	End.	
	Head.	*Crank.*
Cut-off, per cent. of stroke,	26·40	19·83
Release, per cent. of stroke,	75·17	62·91
Compression, per cent. of stroke,	12·56	12·56
Absolute pressure at cut-off,	105·30	104·50
Absolute pressure at release,	56·00	49·00
Absolute pressure at compression,	49·00	46·00
Absolute pressure at admission,	73·00	81·00
Volume in cubic feet, at cut-off,	·40045	·32673
Volume in cubic feet, at release,	·76313	·70351
Volume in cubic feet, at compression,	·27210	·25903
Volume in cubic feet, at admission,	·15716	·14718
External work B.T.U., admission,	4·9000	3·5958
External work B.T.U., expansion,	5·0681	4·8380
External work B.T.U., exhaust	3·4571	2 5497
External work B.T.U., compression,	1·2419	1·2749
External work B.T.U., total,	5 2692	4·6092
Steam from boilers, pounds,	10·3593	8·8704
Steam in clearance, pounds,	2·6906	277·91
Steam, total, pounds,	13·0499	11·6495
Heat in exhaust,	11373·70	9738·80
Heat supplied to engine,	12220·95	10316·00
Sensible heat at admission,	741·45	785·99
Internal heat at admission,	2207·16	2264·20
Sensible heat at cut-off,	3940·42	3510·80
Internal heat at cut-off,	7747·50	6279·00
Sensible heat at release,	3363·00	2901·30
Internal heat at release,	8492·55	6959·30
Cylinder loss during admission,	2991·64	3216·82
Cylinder loss during expansion,	672·44	554·60
Cylinder loss during exhaust,	2535·37	2737·76
Cylinder loss during compression,	536·51	181·83

Low-pressure Cylinder.

	End.	
	Head.	*Crank.*
Cut-off, per cent. of stroke,	36·18	24·48
Release, per cent. of stroke,	88·23	87 72
Compression, per cent. of stroke,	33·82	22·80
Absolute pressure at cut-off,	25·50	26·50
Absolute pressure at release,	12·00	9·70
Absolute pressure at compression,	3·00	3·00
Absolute pressure at admission,	22·00	19·00
Volume in cubic feet at cut-off,	1·2209	·92491

	End.	
	Head.	*Crank.*
Volume in cubic feet at release,	2·3974	2·3752
Volume in cubic feet at compression,	1·0359	·76953
Volume in cubic feet at admission,	·3142	·3192
Volume in cubic feet of space in pressure plate,	·12819	·12819
External work B.T.U., admission,	5·4233	3·5390
External work B.T.U., expansion,	4·1360	4·3582
External work B.T.U., exhaust,	·4109	·5811
External work B.T.U., compression,	1·5339	·9773
Total,	7·6146	6·3388
Steam from boiler, pounds,	10·3593	8·8704
Steam clearance, pounds,	1·7418	1·5387
Steam, total, pounds,	12·1011	10·4091
Heat of condensed steam,	1023·50	876·40
Condensing water, pounds,	108·937	93·279
Heat given to condensing water,	9608·30	8227·20
Heat supplied to engine,	11373·70	9738·80
Sensible heat at admission,	351·51	298·39
Internal heat at admission,	1528·00	1362·50
Sensible heat at cut-off,	2599·20	2208·30
Internal heat at cut-off,	6768·20	5324·50
Sensible heat at release,	1980·00	1611·70
Internal heat at release,	6783·50	5694·20
Total heat in steam at beginning of compression,	935·66	695·07
Heat confined in pressure plate,	521·69	465·36
Cylinder loss during admission,	3343·48	3512·99
Cylinder loss during expansion,	331·39	674·28
Cylinder loss during exhaust,	2763·37	2434·66
Cylinder loss during compression,	268·77	402·73

SUMMARY OF RESULTS.

High-pressure Cylinder.

	End.	
	Head. Per Cent.	*Crank. Per Cent.*
Heat lost by initial condensation,	24·48	31·18
Heat restored during expansion,	5·50	5·38
Heat rejected during exhaust,	20·75	28·11
Heat lost during compression,	4·39	1·76
Heat utilized, work (actual efficiency),	4·31	4·47
Thermo-dynamic efficiency,	8·77	8·77
Efficiency compared with ideal,	49·10	50·90
Quality of steam entering (per calorimeter),	95·50	95·50
Quality of steam at cut-off (computed),	74·19	67·33

	End.	
	Head. *Per Cent.*	*Crank.* *Per Cent.*
Quality of steam at release (computed),	78·01	71·07
Quality of steam at admission (assumed),	100·00	100·00
Quality of steam in exhaust (computed),	104·00	104·00
Low-pressure Cylinder.		
Heat lost by initial condensation,	29·40	36·07
Heat restored during expansion,	2·91	6·92
Heat rejected during exhaust,	24·30	25·00
Heat lost during compression,	2 36	4·13
Heat utilized, work (actual efficiency),	6·69	6·51
Thermo-dynamic efficiency,	15·66	15·66
Efficiency compared with ideal,	42·70	41·56
Quality of steam entering (per calorimeter),	93·30	93·30
Quality at cut-off (computed),	64·22	50·63
Quality at release (computed),	64·76	54·00
Quality at admission (assumed),	100·00	100·00
Quality of steam in exhaust (computed),	90·12	102·00

Averaging the given values for the head and crank ends for each of the two cylinders, the following values are obtained:

	Cylinders.		
	H.P. *Per Cent.*		*L.P.* *Per Cent.*
Quality of steam entering (per calorimeter),	95·50		93·30
Quality of steam at cut-off (computed),	70·76		57·42
Quality of steam at release (computed),	74·54		59·38
Quality of steam at admission (assumed),	100·00		100·00
Quality of steam in exhaust (computed),	104 00		96·06
Heat lost by initial condensation,	27·83		32·73
Heat restored during expansion,	5·44		4·91
Heat rejected during exhaust,	24·43		24·65
Heat lost during compression,	3·07		3·24
Heat utilized, work (actual efficiency),	4·39		6·60
Total,		10·99	
Thermo-dynamic efficiency,	8·77		15·66
Total,		24·43	
Efficiency compared wi h ideal,	50·00		42·13
Mean,		46·07	

Losses by external radiation could not be measured and set apart; but the engine cylinders were well covered and lagged, and this loss may be estimated as about five per

cent. The form of valve used in this engine is such as, while giving large and free opening of ports, will at the same time vary somewhat the volume of clearances; but not sufficiently, probably, to affect the deductions to be made from the trial and its resultant data. The machine was under loaded, according to the builder's schedule and the condenser could not be supplied with as large a volume of condensing water as was desired by him. These facts must be kept in mind in judging the results as a gauge of the value of the engine as a thermo-dynamic machine. Could water have been obtained in sufficient quantity to produce a vacuum of twenty-six inches, instead of twenty-three, the mean effective pressure of the low-pressure cylinder would have been increased to about 25·5 pounds and nearly six per cent. more power would have been secured, with a gain in economy of about five per cent. Increasing the speed from 201 to its rated value, 250, would also have permitted a gain by reduction of internal wastes of four or five per cent., as computed, from 41·11 per cent. to 36·9, and the steam per hour and per horse-power would, in such case, have become 18·5 pounds, nearly, with the low vacuum, and about 17·75 with the higher vacuum ordinarily obtainable. These figures have been frequently approached by good builders, under favorable conditions.* About twenty pounds is commonly thought good work. The uneven distribution of work between the two ends of the cylinders and the fact that the large cylinder under the circumstances described, performed more than its share of the total work, tell against the machine and reduce the efficiency as found below that which should be attained under more favorable conditions. These facts do not affect the value of the data for present purposes.

Comparing these results with the computations given in the opening portion of this paper, it is seen that the total ratio of expansion was here not far from that found most economical in the earlier investigation, and that the consumption of steam is in close accord with the figures there

* *Manual of the Steam Engine*, part i, chap. vi.

obtained and the duty substantially as shown in the accompanying curve, *Fig. 2*. The deduction thus to be drawn is that the constants assumed in the tabulated work are substantially correct for an engine of this class, of good design and construction and operated under ordinarily favorable conditions. The table of engine efficiencies given above may therefore be taken as a probably safe guide in the design of such engines, assuming that correct proportion of volume of cylinders and the best ratios of expansion are adopted for the cases to be met. These proportions are

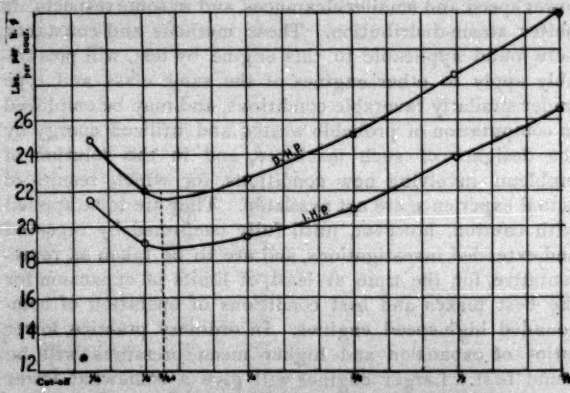

FIG. 2.—Steam consumption. (Compound engine.)

never those found to give minimum cost of steam and fuel, however, and are always such as will exact lower ratios of expansion and smaller ratios of cylinder volumes than those giving maximum fuel economy and highest engine duty. Just to what extent this discrepancy will exist will be determined by costs of engine and of value of fuel and attendance. The best figure is usually two-thirds or three-fourths the value of these ratios, as identified by the processes here described.

* *Manual of the Steam Engine*, part i, chap. vii.

The general facts of the case are that the high-speed engine, with its positive valve motion, its single valve system and its usually large clearances, notwithstanding its advantage of high speed of piston and of rotation, gains enough by compounding to barely compensate the losses due those features which, though having special advantage mechanically, are sources of loss thermo-dynamically. It thus happens that the same process of computation of wastes being resorted to, the constants employed may be substantially the same as those obtained by experiment from the older type of four-valve, detachable gear, with its lower speed and smaller clearances, and in some respects, its better steam-distribution. These methods and constants, here found applicable to this engine by test, will presumably apply to other engines of the same class and type under similarly favorable conditions, and may be employed in computation of probable wastes and utilized energy by the designer of such machines, and in the solution of problems involving new conditions, for which results of actual experience are not available. They are to be applied with caution, however, until fully confirmed by repeated and extended investigations, and are to be taken as representative, for the time at least, of limits of expansion for the best makes and best conditions of operation of compounded high-speed engines. In ordinary practice, lower ratios of expansion and higher mean pressures will be found best. Larger engines will give a somewhat lower curve than that shown in *Fig. 2*; smaller or more wasteful engines will give a higher locus for the curve.

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THERMO-DYNAMICS OF IDEAL AND REAL ENGINES.

r	Cut-off.	Initial Pressure, Pounds per Sq. In.	Terminal Pressure Pounds per Sq. In.	Terminal Pressure Pounds per Sq. Ft.	Indicated Power.	Steam per I.H.P. per Hour (Ideal) W_i.	Internal Waste Coëffic. $\frac{a}{d}\sqrt{\frac{r}{n}}$	Internal Waste, Pounds per I.H.P. and per Hour.	External Waste, Pounds per I.H.P. and per Hour.	Total Waste, Pounds per I.H.P. and per Hour.	Total Consumption Pounds per I.H.P. and per Hour.	Same per D.H.P.
16	1–16	75	3·22	463·7	3·100	*15·85*	1·234	19·56	3·30	22·86	38·71	45·54
8	1/8	75	7·08	1,020	6·42	*15·32*	·87287	13·37	1·50	14·93	*30·25*	*35·58*
4	1/4	75	15·55	2,239	11·77	*16·72*	·61720	10·32	·847	11·167	*27·887*	*32·80*
2·7	3/8	75	24·79	3,408	14·97	*18·48*	·50710	9·88	·666	10·546	*30·026*	*35·32*
2	1/2	75	34·15	4,918	17·85	*21·44*	·43650	9·71	·555	10·265	*32·51*	*38·24*
1·6	5/8	75	44·00	6,336	19·90	*24·76*	·3900	9·66	·502	10·169	*34·92*	*41·08*
16	1–16	95	4·08	588	4·83	*13·74*	1·234	15·74	1·663	17·393	30·133	35·45
8	1/8	95	8·97	1,292	9·31	*13·21*	·87287	11·53	·969	12·499	*25·71*	*30·24*
4	1/4	95	19·70	2,837	15·97	*15·42*	·61720	9·09	·566	9·656	*25·076*	*29·50*
2·7	3/8	95	30·77	4,431	20·58	*17·72*	·50710	8·99	·498	9·418	*27·14*	*31·93*
2	1/2	95	43·26	6,229	24·20	*20·34*	·43650	8·88	·375	9·255	*29·595*	*34·81*
1·6	5/8	95	55·72	8,024	26·62	*23·11*	·3900	9·02	·333	9·353	*32·46*	*38·19*
16	1–16	115	4·94	711·8	6·18	*11·91*	1·234	14·70	1·360	16·060	27·97	32·91
8	1/8	115	10·86	1,564	11·62	*12·68*	·87287	11·07	·755	11·825	*24·55*	*28·82*
4	1/4	115	23·84	3,433	19·68	*14·97*	·61720	9·24	·415	9·655	*26·48*	*28·97*
2·7	3/8	115	37·25	5,364	25·28	*17·35*	·50710	8·80	·331	9·131	*28·836*	*31·15*
2	1/2	115	52·36	7,540	29·64	*19·88*	·43650	8·68	·296	8·956	*30·00*	*33·92*
1·6	5/8	115	67·46	9,714	32·60	*22·60*	·3900	8·82	·251	9·071	*31·67*	*37·26*
16	1–16	135	5·8	835·6	7·534	*11·38*	1·234	14·05	1·043	15·093	26·473	31·14
8	1/8	135	12·75	1,836	13·91	*12·32*	·87287	10·75	·504	11·314	*23·63*	*27·80*
4	1/4	135	27·99	4,031	23·37	*14·67*	·61720	9·05	·344	9·394	*24·06*	*28·30*
2·7	3/8	135	43·73	6,297	30·00	*16·96*	·50710	8·60	·263	8·863	*25·82*	*30·37*
2	1/2	135	61·47	8,852	35·00	*19·54*	·43650	8·53	·283	8·756	*28·29*	*33·28*
1·6	5/8	135	79·19	11,403	38·50	*22·25*	·3900	8·68	·208	8·888	*31·13*	*36·62*
16	1–16	155	6·66	959·4	8·89	*10·98*	1·234	13·55	·836	14·336	25·36	28·84
8	1/8	155	14·63	2,106	16·20	*12·05*	·87287	10·52	·402	10·982	*23·03*	*27·09*
4	1/4	155	32·14	4,628	27·00	*14·41*	·61720	8·89	·274	9·164	*23·57*	*27·73*
2·7	3/8	155	50·2	7,223	34·58	*16·72*	·50710	8·48	·213	8·693	*25·41*	*29·89*
2	1/2	155	70·58	10.163	40·50	*19·28*	·43650	8·41	·182	8·592	*27·87*	*32·74*
1·6	5/8	155	90·92	13.092	44·48	*21·95*	·3900	8·57	·164	8·344	*30·68*	*36·26*

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ON LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.*

BY NIKOLA TESLA.

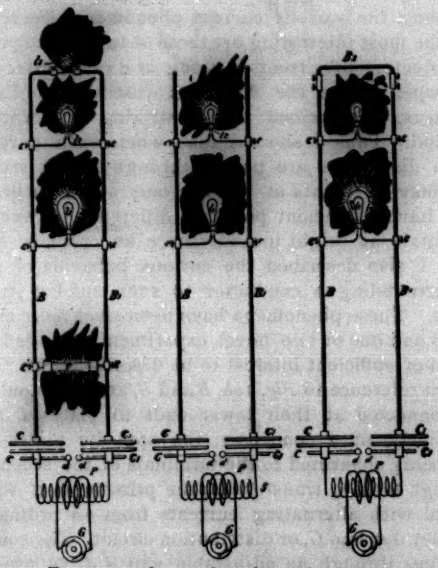
[*Continued from p. 177.*]

Among the various current phenomena observed, perhaps, the most interesting are those of impedance presented by conductors to currents varying at a rapid rate. In my first paper before the American Institute of Electrical Engineers, I described a few striking observations of this kind. Thus I showed that when such currents or sudden discharges are passed through a thick metal bar there may be points at the bar only a few inches apart, which have a sufficient potential difference between them to maintain at bright incandescence an ordinary filament lamp. I also described the curious behavior of rarefied gas surrounding a conductor to such sudden rushes of current. These phenomena have been since more carefully studied and one or two novel experiments of this kind are deemed of sufficient interest to be described here.

With reference to *Fig.* 19*a*, *B* and B_1 are very stout copper bars connected at their lower ends to plates *C* and C_1, respectively, of a condenser, the opposite plates of the latter being connected to the terminals of the secondary *S*, of a high tension transformer, the primary *P*, of which, is supplied with alternating currents from an ordinary low frequency dynamo *G*, or distribution circuit. The condenser discharges through an adjustable gap *d d*, as usual. By establishing a rapid vibration it was found quite easy to perform the following curious experiment: The bars *B* and B_1 were joined at the top by a low voltage lamp l_3; a little lower, was placed, by means of clamps *c c*, a fifty-volt lamp l_2, and still lower another 100-volt lamp l_1, and finally at a certain

* A lecture delivered before the Franklin Institute, at Philadelphia, February 24, 1893, and before the National Electric Light Association, at St. Louis, March 1, 1893.

distance below the latter lamp, an exhausted tube *T*. By carefully determining the positions of these devices it was found practicable to maintain them all at their proper illuminating power. Yet they were all connected in multiple arc to the two stout copper bars and required widely different pressures. This experiment requires, of course, some time for adjustment, but is quite easily performed.



FIGS. 19*a*, 19*b*, 19*c*.—Impedance phenomena.

In *Figs. 19b* and *19c*, two other experiments are illustrated which, unlike the previous experiment, do not require very careful adjustments. In *Fig. 20b*, two lamps l_1 and l_2, the former a 100-volt and the latter a fifty-volt are placed in certain positions as indicated, the 100-volt lamp being below the fifty-volt lamp. When the arc is playing at *d d*, and the sudden discharges passed through the bars *B B*, the fifty-volt lamp will, as a rule, burn brightly, or at least this

result is easily secured, while the 100-volt lamp will burn very low or remain quite dark, *Fig. 19b*. Now the bars *B B*, may be joined at the top by a thick cross bar B_2, and it is quite easy to maintain the 100-volt lamp at full candle-power while the fifty-volt lamp remains dark, *Fig. 19c*. These results, as I have previously pointed out, should not be considered to be due exactly to frequency, but rather to the time rate of change which may be great, even with low frequencies. A great many other results of the same kind, equally interesting, especially to those who are only used to manipulate steady currents, may be obtained and they afford precious clues in investigating the nature of electric currents.

In the preceding experiments I have already had occasion to show some light phenomena and it would be now proper to study these in particular; but to make this investigation

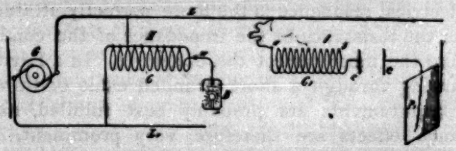


FIG. 20.—Plan followed in observing the effects of resonance.

more complete, I think it necessary first to make a few remarks on the subject of electrical resonance which must always be observed in carrying out these experiments.

On Electrical Resonance.—The effects of resonance are being more and more noted by engineers and are becoming of great importance in the practical operation of apparatus of all kinds with alternating currents. A few general remarks may therefore be made concerning these effects. It is clear that if we succeed in employing the effects of resonance practically in the operation of electric devices the return wire will, as a matter of course, become unnecessary, for the electric vibration may be conveyed with one wire just as well, and sometimes even better, than with two. The question first to answer is, then, Whether pure resonance effects are producible? Theory and experiment both show that such is impossible in nature, for as the oscilla-

tion becomes more and more vigorous the losses in the vibrating bodies and environing media rapidly increase and necessarily check the vibration which otherwise would go on increasing forever. It is a fortunate circumstance that pure resonance is not producible, for if it were there is no telling what dangers might lie in wait for the innocent experimenter. But to a certain degree resonance is producible, the magnitude of the effects being limited by the imperfect conductivity and imperfect elasticity of the mediator, generally stated by frictional losses. The smaller these losses, the more striking are the effects. The same is the case in mechanical vibration. A stout steel bar may be set in vibration by drops of water falling upon it at proper intervals; and with glass, which is more perfectly elastic, the resonance effect is still more remarkable, for a goblet may be burst by singing into it a note of the proper pitch. The electrical resonance is the more perfectly attained, the smaller the resistance or the impedance of the conducting path and the more perfect the dielectric. In a Leyden jar discharging through a short stranded cable of thin wires these requirements are probably best fulfilled, and the resonance effects are therefore very prominent. Such is not the case with dynamo machines, transformers and their circuits, or with commercial apparatus in general in which the presence of iron cores complicates or renders impossible the action. In regard to Leyden jars with which resonance effects are frequently demonstrated, I would say that the effects observed are often *attributed* but are seldom *due* to true resonance, for an error is quite easily made in this respect. This may positively be demonstrated by the following experiment: Take, for instance, two large insulated metallic plates or spheres, which I shall designate *A* and *B*, place them at a certain small distance apart and charge them from a frictional or influence machine to a potential so high that just a slight increase of the difference of potential between them will cause the small air or insulating space to break down. This is easily reached by making a few preliminary trials. If now another plate—fastened on an insulating handle

and connected by a wire to one of the terminals of a high tension secondary of an induction coil, which is maintained in action by an alternator (preferably high frequency)—is approached to one of the charged bodies *A* or *B*, so as to be nearer to either one of them, the discharge will invariably occur between them; at least it will, if the potential of the coil in connection with the plate is sufficiently high. But the explanation of this is to be sought in the fact that the approached plate acts inductively upon the bodies *A* and *B* and causes a spark to pass between them. When this spark occurs, the charges, which were previously imparted to these bodies from the influence machine, must needs be lost, since the bodies are brought in electrical connection through the arc formed. Now this arc is formed whether there be resonance or not. But, even if the spark would not be produced, there is still an alternating E. M. F. set up between the bodies when the plate is brought near one of them; therefore, the approach of the plate, if it *does* not always, actually, will, at any rate, *tend*, to break down the air space by inductive action. Instead of the spheres, or plates, *A* and *B*, we may take the coatings of a Leyden jar with the same result, and in place of the machine, which is preferably a high frequency alternator, because it is more suitable for the experiment and also for the argument, we may take another Leyden jar or battery of jars. When such jars are discharging through a circuit of low resistance the same is traversed by currents of very high frequency. The plate may now be connected to one of the coatings of the second jar, and when it is brought near to the first jar just previously charged to a high potential from an influence machine, the result is the same as before, and the first jar will discharge through a small air space upon the second being caused to discharge. But both jars and their circuits need not be tuned any closer than a basso profundo is to the note produced by a mosquito, as small sparks will be produced through the air space or at least the latter will be considerably more strained owing to the setting up of an alternating E. M. F. by induction, which takes place when one of the jars

begins to discharge. Again another error of a similar nature is quite easily made. If the circuits of the two jars are run parallel and close together, and the experiment has been performed of discharging one by the other, and now a coil of wire be added to one of the circuits whereupon the experiment does not succeed, the conclusion that this is due to the fact that the circuits are now not tuned, would be far from being safe. For the two circuits act as condenser coating and the addition of the coil to one of them is equivalent to bridging them, at the point where the coil is placed, by a small condenser, and the effect of the latter might be to prevent the spark from jumping through the discharge space by diminishing the alternating E. M. F. acting across the same. All these remarks, and many more which might be added but for fear of wandering too far from the subject, are made with the pardonable intention of cautioning the unsuspecting student, who might gain an entirely unwarranted opinion of his skill when seeing every experiment succeed; but they are in no way thrust upon the experienced as novel observations.

In order to make reliable observations of electric resonance effects it is very desirable, if not necessary, to employ an alternator giving currents which rise and fall harmonically, as in working with make- and break-currents the observations are not always trustworthy, since many phenomena, which depend on the rate of change, may be produced with frequencies widely different. Even when making such observations with an alternator one is apt to be mistaken. When a circuit is connected to an alternator there are an infinite number of values for capacity and self-induction which, in conjunction, will satisfy the condition of resonance. So there are in mechanics an infinite number of tuning forks which will respond to a note of a certain pitch, or loaded springs which have a definite period of vibration. But the resonance will be most perfectly attained in that case in which the motion is effected with the greatest freedom. Now in mechanics, considering the vibration in the common medium—that is, air—it is of com-

paratively little importance whether one tuning fork be somewhat larger than another, because the losses in the air are not very considerable. One may, of course, enclose a tuning fork in an exhausted vessel and by thus reducing the air resistance to a minimum obtain better resonant action. Still the difference would not be very great. But it would make a great difference if the tuning fork were immersed in mercury. In the electrical vibration it is of enormous importance to arrange the conditions so that the vibration is effected with the greatest freedom. The magnitude of the resonance effect depends, under otherwise equal conditions, on the quantity of electricity set in motion or on the strength of the current driven through the circuit. But the circuit opposes the passage of the currents by reason of its impedance and therefore, to secure the best action, it is necessary to reduce the impedance to a minimum. It is impossible to overcome it entirely, but merely in part, for ohmic resistance cannot be overcome. But when the frequency of the impulses is very great, the flow of the current is practically determined by self-induction. Now, self-induction can be overcome by combining it with capacity. If the relation between these is such, that at the frequency used they annul each other; that is, have such values as to satisfy the condition of resonance and the greatest quantity of electricity is made to flow through the external circuit, then the best result is obtained. It is simpler and safer to join the condenser in series with the self-induction. It is clear that in such combinations there will be, for a given frequency, and considering only the fundamental vibration, values which will give the best result, with the condenser in shunt to the self-induction coil; of course, more such values than with the condenser in series. But practical conditions determine the selection. In the latter case in performing the experiments one may take a small self-induction and a large capacity or a small capacity and a large self-induction, but the latter is preferable, because it is inconvenient to adjust a large capacity by small steps. By taking a coil with a very large self-induction the critical capacity is reduced to a very small

value, and the capacity of the coil itself may be sufficient. It is easy, especially by observing certain artifices, to wind a coil through which the impedance will be reduced to the value of the ohmic resistance only and for any coil there is, of course, a frequency at which the maximum current will be made to pass through the coil. The observation of the relation between self-induction, capacity and frequency is becoming important in the operation of alternate current apparatus, such as transformers or motors, because by a judicious determination of the elements the employment of an expensive condenser becomes unnecessary. Thus it is possible to pass through the coils of an alternating current motor under the normal working conditions the required current with a low E. M. F. and do away entirely with the false current, and the larger the motor the easier such a plan becomes practicable; but it is necessary for this to employ currents of very high potential or high frequency.

In *Fig. 201* is shown a plan which has been followed in the study of the resonance effects by means of a high frequency alternator. *C* is a coil of many turns, which is divided in small separate sections for the purposes of adjustment. The final adjustment was made sometimes with a few thin iron wires (though this is not always advisable) or with a closed secondary. The coil *C* is connected with one of its ends to the line *L* from the alternator *G* and with the other end to one of the plates c of a condenser $c\ c_1$, the plate (c_1) of the latter being connected to a much larger plate P_1. In this manner both capacity and self-induction were adjusted to suit the dynamo frequency.

As regards the rise of potential through resonant action, of course, theoretically, it may amount to anything since it depends on self-induction and resistance and since these may have any value. But in practice one is limited in the selection of these values, and besides these, there are other limiting causes. One may start with (say) 1,000 volts and raise the E. M. F. to fifty times that value, but one cannot start with 100,000 and raise it to ten times that value because of the losses in the media which are great, espe-

cially if the frequency is high. It should be possible to start with, for instance, two volts from a high or low frequency circuit of a dynamo and raise the E. M. F. to many hundred times that value. Thus coils of the proper dimensions might be connected each with only one of its ends to the mains from a machine of low E. M. F., and though the circuit of the machine would not be closed in the ordinary acceptance of the term, yet the machine might be burned out if a proper resonance effect would be obtained. I have not been able to produce, nor have I observed with currents from the dynamo machine, such great rises of potential. It is possible, if not probable, that with currents obtained from apparatus containing iron the disturbing influence of the latter is the cause that these theoretical possibilities cannot be realized. But if such is the case I attribute it solely to the hysteresis and Faucault current losses in the core. Generally it was necessary to transform upward, when the E. M. F. was very low, and usually an ordinary form of induction coil was employed, but sometimes the arrangement illustrated in *Fig. 20II*, has been found to be convenient. In this case a coil C is made in a great many sections, a few of these being used as the primary. In this manner both primary and secondary are adjustable. One end of the coil is connected to the line L_1 from the alternator, and the other line L is connected to the intermediate point of the coil. Such a coil with adjustable primary and secondary will be found also convenient in experiments with the disruptive discharge. When true resonance is obtained the top of the wave must, of course, be on the free end of the coil as, for instance, at the terminal of the phosphorescence bulb B. This is easily recognized by observing the potential of a point on the wire w nearer to the coil.

In connection with resonance effects and the problem of transmission of energy over a single conductor which was previously considered, I would say a few words on a subject which constantly fills my thoughts and which concerns the welfare of all. I mean the transmission of intelligible signals or perhaps even power to any distance without the

use of wires. I am becoming daily more convinced of the practicability of the scheme; and though I know full well that the great majority of scientific men will not believe that such results can be practically and immediately realized yet I think that all consider the developments in recent years by a number of workers to have been such as to encourage thought and experiment in this direction. My conviction has grown so strong that I no longer look upon this plan of energy or intelligence transmission as a mere theoretical possibility, but as a serious problem in electrical engineering, which must some day be carried out. The idea of transmitting intelligence without wires is the natural outcome of the most recent results of electrical investigations. Some enthusiasts have expressed their belief that telephony to any distance by induction through the air is possible. I cannot stretch my imagination so far, but I do firmly believe that it is practicable to disturb by means of powerful machines the electrostatic condition of the earth and thus transmit intelligible signals and perhaps power. In fact what is there against the carrying out of such a scheme? We now know that electric vibration may be transmitted through a single conductor. Why then not try to avail ourselves of the earth for this purpose? We need not be frightened by the idea of distance. To the weary wanderer counting the mile posts the earth may appear very large, but to that happiest of all men the astronomer, who gazes at the heavens and by their standard judges the magnitude of our globe, it appears very small. And so I think it must seem to the electrician, for when he considers the speed with which an electric disturbance is propagated through the earth all his ideas of distance must completely vanish.

A point of great importance would be first to know what is the capacity of the earth? and what charge does it contain if electrified? Though we have no positive evidence of a charged body existing in space without other oppositely electrified bodies being near, there is a fair probably that the earth is such a body, for by whatever process it was separated from other bodies—and this is the accepted view

of its origin—it must have retained a charge, as it occurs in all processes of mechanical separation. If it be a charged body insulated in space, its capacity should be extremely small less than one-thousanth of a farad. But the upper strata of the air are conducting, and so, perhaps, is the medium in free space beyond the atmosphere, and these may contain an opposite charge. Then the capacity might be incomparably greater. In any case it is of the greatest importance to get an idea of what quantity of electricity the earth contains. It is difficult to say whether we shall ever acquire this necessary knowledge, but there is hope that we may, and that is, by means of electrical resonance. If ever we can ascertain at what period the earth's charge, when disturbed, oscillates with respect to an oppositely electrified system or known circuit, we shall know a fact possibly of the greatest importance to the welfare of the human race. I propose to seek for the period by means of an electrical oscillator, or a source of alternating electric current. One of the terminals of the source would be connected to earth, as, for instance, to the city water mains, the other to an insulated body of large surface. It is possible that the outer conducting air strata or free space contains an opposite charge, and that, together with the earth, they form a condenser of very large capacity. In such case the period of vibration may be very low and an alternating dynamo machine might serve for the purpose of the experiment. I would then transform the current to a potential as high as it would be found possible and connect the ends of the high tension secondary to the ground and to the insulated body. By varying the frequency of the currents and carefully observing the potential of the insulated body and watching for the disturbance at various neighboring points of the earth's surface resonance might be detected. Should, as the majority of scientific men in all probability believe, the period be extremely small, then a dynamo machine would not do and a proper electrical oscillator would have to be produced and perhaps it might not be possible to obtain such rapid vibrations. But whether this be possible or not, and whether the earth contains a charge or not, and whatever may be its period of vibration,

it certainly is possible—for of this we have daily evidence—to produce some electrical disturbance sufficiently powerful to be perceptible by suitable instruments at any point of the earth's surface.

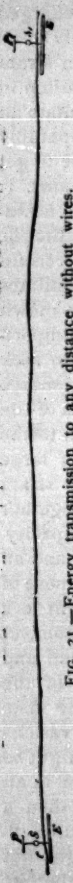


FIG. 21.—Energy transmission to any distance without wires.

Assume that a source of alternating currents S be connected, as in *Fig. 21*, with one of its terminals to earth (conveniently to the water mains) and with the other to a body of large surface P. When the electric oscillation is set up there will be a movement of electricity in and out of P, and alternating currents will pass through the earth, converging to, or diverging from the point C where the ground connection is made. In this manner neighboring points on the earth's surface within a certain radius will be disturbed. But the disturbance will diminish with the distance, and the distance at which the effect will still be perceptible will depend on the quantity of electricity set in motion. Since the body P is insulated, in order to displace a considerable quantity the potential of the source must be excessive, since there would be limitations as to the surface of P. The conditions might be adjusted so that the generator or source S will set up the same electrical movement as though its circuit were closed. Thus it is certainly practicable to impress an electric vibration at least of a certain low period upon the earth, by means of proper machinery. At what distance such a vibration might be made perceptible can only be conjectured. I have on another occasion considered the question how the earth might behave to electric disturbances. There is no doubt that, since in such an experiment the electrical density at the surface could be but extremely small considering the size of the earth, the air would not act as a very disturbing factor, and there would be not much energy lost through the action of the air which would be the case if the density were great. Theoretically,

then, it could not require a great amount of energy to produce a disturbance perceptible at great distance, or even all over the surface of the globe. Now it is quite certain that at any point within a certain radius of the source S a properly adjusted self-induction and capacity device can be set in action by resonance. But not only can this be done, but another source S_1, *Fig. 21*, similar to S, or any number of such sources can be set to work in synchronism with the latter, and the vibration thus intensified and spread over a large area, or a flow of electricity produced to or from the source S_1 if the same be of opposite phase to the source S. I think that beyond doubt it is possible to operate electrical devices in a city through the ground or pipe system by resonance from an electrical oscillator located at a central point. But the practical solution of this problem would be of incomparably smaller benefit to man than the realization of the scheme of transmitting intelligence or perhaps power to any distance through the earth or environing medium. If this is at all possible, distance does not mean anything. Proper apparatus must first be produced by means of which the problem can be attacked, and I have devoted much thought to this subject. I am firmly convinced that it can be done, and hope that we shall live to see it done.

On the Light Phenomena produced by High Frequency Currents of High Potential and General Remarks Relating to the Subject.—Returning now to the light effects which it has been the chief object to investigate, it is thought proper to divide these effects in four classes:

(1) Incandescence of a solid.

(2) Phosphorescence.

(3) Incandescence or phosphorescence of a rarefied gas.

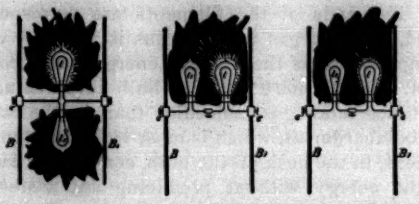
(4) Luminosity produced in a gas at ordinary pressure.

The first question is: How are these luminous effects produced? In order to answer this question as satisfactorily as I am able to do in the light of accepted views and with the experience acquired, and to add some interest to this demonstration, I shall dwell here upon a feature which I consider of great importance, inasmuch as it promises,

besides, to throw a better light upon the nature of most of the phenomena produced by high frequency electric currents. I have on other occasions pointed out the great importance of the presence of the rarefied gas, or atomic medium in general, around the conductor through which alternate currents of high frequency are passed, as regards the heating of the conductor by the currents. My experiments described some time ago have shown that the higher the frequency and potential difference of the currents, the more important becomes the rarefied gas in which the conductor is immersed, as a factor of the heating. The potential difference, however, is, as I then pointed out, a more important element than the frequency. When both of these are sufficiently high, the heating may be almost entirely due to the presence of the rarefied gas. The experiments to follow will show the importance of the rarefied gas, or generally of gas at ordinary or other pressure as regards the incandescence or other luminous effects produced by currents of this kind.

I take two ordinary fifty-volt sixteen candle-power lamps which are in every respect alike, with the exception that one has been opened at the top and the air has filled the bulb, while the other is at the ordinary degree of exhaustion of commercial lamps. When I attach the lamp which is exhausted to the terminal of the secondary of the coil, which I have already used as in experiments illustrated in *Fig. 15a*, for instance, and turn on the current, the filament as you have before seen comes to high incandescence. When I attach the second lamp, which is filled with air, instead of the former, the filament still glows, but much less brightly. This experiment illustrates only in part the truth of the statements before made. The importance of the filament's being immersed in rarefied gas is plainly noticeable but not to such a degree as might be desirable. The reason is that the secondary of this coil is wound for low tension, having only 150 turns, and the potential difference at the terminals of the lamp is therefore small. Were I to take another coil with many more turns in the secondary, the effect would be increased, since it depends partially on the potential differ-

ence, as before remarked. But since the effect likewise depends on the frequency, it may be properly stated that it depends on the time rate of the variations of the potential difference. The greater this variation the more important becomes the gas as an element of heating. I can produce a much greater rate of variation in another way, which, besides, has the advantage of doing away with the objections, which might be made in the experiment just shown, even if both the lamps were connected in series or multiple arc to the coil, namely, that in consequence of the reactions existing between the primary and secondary coil the conclusions are rendered uncertain. This result I secure by charging from an ordinary transformer, which is fed from the alternating current supply station, a battery of condensers,



FIGS. 22*a*, 22*b*, 22*c*.—Showing the effect of the presence of a gaseous medium.

and discharging the latter directly through a circuit of small self-induction, as before illustrated in *Figs. 19a, 19b, 19c.*

In *Figs. 22a, 22b* and *22c*, the heavy copper bars $B\ B_1$ are connected to the opposite coatings of a battery of condensers, or generally in such way that the high frequency or sudden discharges are made to traverse them. I connect first an ordinary fifty-volt incandescent lamp to the bars by means of the clamps *c c*. The discharges being passed through the lamp, the filament is rendered incandescent, though the current through it is very small, and would not be nearly sufficient to produce a visible effect under the conditions of ordinary use of the lamp. Instead of this, I now attach to the bars another lamp exactly like the first, but with the seal broken off, the bulb being therefore

filled with air at ordinary pressure. When the discharges are directed through the filament, as before, it does not become incandescent. But the result might still be attributed to one of the many possible reactions. I therefore connect both the lamps in multiple arc, as illustrated in *Fig. 22a*. Passing the discharges through both the lamps, again the filament in the exhausted lamp l glows very brightly while that in the non-exhausted lamp l_1 remains dark, as previously. But it should not be thought that the latter lamp is taking only a small fraction of the energy supplied to both the lamps; on the contrary, it may consume a considerable portion of the energy and it may become even hotter than the one which burns brightly. In this experiment the potential difference at the terminals of the lamps varies in sign theoretically 3,000,000 or 4,000,000 times a second. The ends of the filaments are correspondingly electrified, and the gas in the bulbs is violently agitated and a large portion of the supplied energy is thus converted into heat. In the non-exhausted bulb there being a few million times more gas molecules than in the exhausted one, the bombardment, which is most violent at the ends of the filament, in the neck of the bulb, consumes a large portion of the energy without producing any visible effect. The reason is that, there being many molecules, the bombardment is quantitatively considerable, but the individual impacts are not very violent, as the speeds of the molecules are comparatively small, owing to the small free path. In the exhausted bulb, on the contrary, the speeds are very great and the individual impacts are violent, and therefore better adapted to produce a visible effect. Besides, the convection of heat is greater in the former bulb. In both the bulbs the current traversing the filaments is very small, incomparably smaller than that which they require on an ordinary low frequency circuit. The potential difference, however, at the ends of the filaments is very great and might be possibly 20,000 volts or more, if the filaments were straight and their ends far apart. In the ordinary lamp a spark generally occurs between the ends of the filament or between the platinum wires outside, before such a difference of potential can be reached.

It might be objected in the experiment before shown that the lamps, being in multiple arc, the exhausted lamp might take a much larger current, and that the effect observed might not be exactly attributable to the action of the gas in the bulbs. Such objections will lose much weight if I connect the lamps in series, with the same result. When this is done and the discharges are directed through the filaments it is again noted that the filament in the non-exhausted bulb *l* remains dark, while that in the exhausted one (*l*) glows even more intensely than under its normal condition of working, *Fig. 22b*. According to general ideas the current through the filaments should now be the same, were it not modified by the presence of the gas around the filaments.

At this juncture I may point out another interesting feature, which illustrates the effect of the rate of change of potential of the currents. I will leave the two lamps connected in series to the bars $B\ B_1$, as in the previous experiment, *Fig. 22b*, but will presently reduce considerably the frequency of the currents, which was excessive in the experiment just before shown. This I may do by inserting a self-induction coil in the path of the discharges, or by augmenting the capacity of the condensers. When I now pass these low frequency discharges through the lamps, the exhausted lamp *l* again is as bright as before, but it is noted also that the non-exhausted lamp *l* glows, though not quite as intensely as the other. Reducing the current through the lamps, I may bring the filament in the latter lamp to redness, and, though the filament in the exhausted lamp *l* is bright, *Fig. 22c*, the degree of its incandescence is much smaller than in *Fig. 22b*, when the currents were of a much higher frequency.

In these experiments the gas acts in two opposite ways in determining the degree of the incandescence of the filaments; that is, by convection and bombardment. The higher the frequency and potential of the currents, the more important becomes the bombardment. The convection, on the contrary, should be the smaller, the higher the frequency. When the currents are steady there is practically no bom-

bardment and convection may therefore with such currents also considerably modify the degree of incandescence and produce results similar to those just before shown. Thus, if two lamps exactly alike, one exhausted and one not exhausted, are connected in multiple arc, or series, to a direct current machine, the filament in the non-exhausted lamp will require a considerably greater current to be rendered incandescent. This result is entirely due to convection and the effect is the more prominent the thinner the filament. Professor Ayrton and Mr. Kilgour some time ago published quantitative results concerning the thermal emissivity by radiation and convection in which the effect of thin wires was clearly shown. This effect may be strikingly illustrated by preparing a number of small short glass tubes, each containing through its axis the thinnest obtainable platinum wire. If these tubes be highly exhausted, a number of them may be connected in multiple arc to a direct current machine and all of the wires may be kept at incandescence with a smaller current than that required to render incandescent a single one of the wires if the tube be not exhausted. Could the tubes be so highly exhausted that convection would be *nil*, then the relative amounts of heat given off by convection and radiation could be determined without the difficulties attending thermal quantitative measurements. If a source of electric impulses of high frequency and very high potential is employed, a still greater number of the tubes may be taken and the wires rendered incandescent by a current not capable of warming perceptibly a wire of the same size immersed in air at ordinary pressure, and conveying the energy to all of them.

I may here describe a result which is still more interesting, and to which I have been led by the observation of these phenomena. I noted that small differences in the density of the air produced a considerable difference in the degree of incandescence of the wires, and I thought that, since in a tube, through which a luminous discharge is passed, the gas is generally not of uniform density, a very thin wire contained in the tube might be rendered incandescent at certain places where the density of the gas was low,

while it would remain dark at the places of greater density, where the convection would be greater and the bombardment less intense. Accordingly a tube *t* was prepared, as illustrated in *Fig. 23*, which contained through the middle a very fine platinum wire *w*. The tube was exhausted to a moderate degree, and it was found that when it was attached to the terminal of a high-frequency coil, the platinum wire *w* would, indeed, become incandescent in patches, as illustrated in *Fig. 23*. Later, a number of these tubes with one

FIG. 23.—Curious incandescence of a wire.

or more wires were prepared, each showing this result. The effect was best noted when the striated discharge occurred in the tube, but was also produced when the striæ were not visible, showing that, even then, the gas in the tube was not of uniform density. The position of the striæ was generally such, that the rarefactions corresponded to the places of incandescence, or greater brightness on the wire *w*. But in a few instances, it was noted, that the bright spots on the wire were covered by the dense parts of the

striated discharge as indicated by *l* in *Fig. 23*, though the effect was barely perceptible. This was explained in a plausible way by assuming, that the convection was not widely different in the dense and rarefied places, and that the bombardment was greater on the dense places of the striated discharge. It is, in fact, often observed in bulbs that under certain conditions a thin wire is brought to higher incandescence when the air is not too highly rarefied. This is the case when the potential of the coil is not high enough for the vacuum, but the result may be attributed to many different causes. In all cases this curious phenomenon of incandescence disappears when the tube, or rather the wire, acquires throughout a uniform temperature.

Disregarding now the modifying effect of convection, there are then two distinct causes which determine the incandescence of a wire or filament with varying currents; that is, conduction current and bombardment. With steady currents we have to deal only with the former of these two causes, and the heating effect is a minimum, since the resistance is least to steady flow. When the current is a varying one, the resistance is greater, and hence the heating effect is increased. Thus, if the rate of change of the current is very great, the resistance may increase to such an extent that the filament is brought to incandescence with inappreciable currents, and we are able to take a short and thick block of carbon or other material and bring it to bright incandescence with a current incomparably smaller than that required to bring to the same degree of incandescence an ordinary thin lamp filament with a steady or low frequency current. This result is important, and illustrates how rapidly our views on these subjects are changing, and how quickly our field of knowledge is extending. In the art of incandescent lighting, to view this result in one aspect only, it has been commonly considered as an essential requirement for practical success, that the lamp filament should be thin and of high resistance. But now we know that the resistance to the steady flow of the filament does not mean anything; the filament might as well be short and thick; for if it be immersed in rarefied gas it will

become incandescent by the passage of a small current. It all depends on the frequency and potential of the currents. We may conclude from this, that it would be of advantage, so far as the lamp is considered, to employ high frequencies for lighting, as they allow the use of short and thick filaments and smaller currents.

[*To be concluded.*]

CARBORUNDUM: ITS HISTORY, MANUFACTURE AND USES.

By E. G. Acheson.

[*Read at the stated meeting of the Institute, held June 21, 1893.*]

B represents the less attacked mixture of sand, carbon and salt. This mixture surrounds the other shells. An analysis of a sample taken from the top of the mass gave the following composition:

	Per Cent.
(I) Salts soluble in water,	11·19
(II) Carbon, free,	32·96
(III) Ash (insoluble in water),	55·85

The analysis of part I gave the following results:

	Per Cent.
P_2O_5,	0·02
SO_3,	2·43
MgO,	0·04
CaO,	0·19
Al_2O_3,	0·04
Fe_2O_3,	0·71
NaCl,	96·57

Part III had the composition:

	Per Cent.
SiO_2,	94·28
Fe_2O_3,	1·75
Al_2O_3,	4·24
CaO,	0·21
MgO,	0·14

The composition of this—the outer mass—would, however, be a variable quantity, depending upon the original mixture.

While it is not my intention, nor the purpose of this paper, to enter into any exact statements regarding the cost of manufacturing carborundum, I deem the subject one of sufficient interest to justify some few remarks and figures.

The quantity produced at the present time will average 150 pounds per day of twenty-four hours, requiring an expenditure of seventy-eight horse-power for a like period, or 1,872 horse-power hours, amounting to twelve horse-power hours for each pound produced. Improvements now being introduced, relating to the design of the furnace and current regulations, will, it is expected, reduce this expenditure about twenty per cent. or thirty per cent. The location of the works—in the centre of the great coal fields of Western Pennsylvania—permits of obtaining cheap fuel, for the steam plant, and cheap coke for the use of the carborundum furnaces. The value of this location is not, however, of so great significance at the present time, as it will prove to be with largely increased production, for, while with an output of 150 pounds per day, the fuel constitutes but one-third of the total cost of the power, with an output amounting to ten times that amount, or 1,500 pounds, it would be approximately two-thirds of the cost. The present practice entails a loss of a considerable quantity of the coke, sand and salt, used in charging the furnaces; the amounts required for producing one pound of carborundum being, approximately, four pounds of mixture containing 1·82 pounds of sand, 1·46 pounds of coke, and ·72 pound of salt. Much of this waste is due to difficulties encountered in re-using portions of the mixture left from former charges, this applies particularly to that portion designated in the diagram as *W*, and that portion of the mixture *B* immediately surrounding it.

The furnace as now used does not materially differ from the early form as shown in the diagram. The advisability of furnishing a ready escape for the gases produced, together with the necessity of having refractory and electrically non-conducting walls, has resulted in the continued use of fire-brick for its construction. These are knocked down after each run and built up fresh for the succeeding one, it

having been found that repeated use, without re-building, reduced the output, owing to the walls becoming, in a measure, conducting from incrustations forming thereon. Four carbon electrodes are used at each end, their size being 2 inches in diameter by 12 inches in length. These carbons are, as in the furnace shown, adjustable lengthwise, permitting of the tightening up of their contacts with the mixture and core. The dimensions of the furnace are 18 inches in width by 12 inches in depth and 6 feet in length. The core consists of granular carbon, placed in the form of a sheet, having a width of about 10 inches, depth 1 inch, and in length, extending the distance intervening between the electrodes, about 5½ feet.

A furnace of this construction and capacity requires from seven and one-half to eight hours' time to complete the transformation of a portion of the charge into fifty pounds of carborundum, and three of them are operated every twenty-four hours. The labor required for the preparation of the mixture, building and charging the furnace, operating and discharging the same, for twenty-four hours, consists of the services of two men and two boys. This same amount of labor would, however, be able to attend to the production of probably four times the amount now made.

From these figures and data, it will be concluded that the cost of manufacturing carborundum, on a large scale, need not exceed, and possibly not equal, the present cost of mining corundum and preparing it for the market.

Carborundum, when removed from the furnace, is a mass of crystals, of varying sizes, the greater number being of a size sufficiently small to pass through a sieve having 2,500 meshes to the square inch, and too large to pass through one having 40,000 meshes. These crystals cling together in so loose a manner that comparatively little effort is required to separate them. In the factory this separation is accomplished by throwing the crude lump material into an iron pan, and causing two heavy iron wheels to roll over it—water being introduced to facilitate the action—and the mass is stirred up continually during the grinding process.

After removal from the grinding pan, the carborundum is placed in stone tanks, and treated with dilute sulphuric acid, for a period of seven days, the object of this treatment being the removal of all iron, it having been found necessary to remove this impurity before firing in the kiln, during the manufacture of wheels, as a destruction of the crystals would result from its presence.

The intrinsic value of carborundum is a quantity yet to be determined. That it will find varied uses in the arts and manufactures cannot be doubted, its three prominent characteristics—great hardness, infusibility and incombustibility—are sufficient to warrant its extensive introduction into special lines. Perhaps no other use to which it can be put will equal in importance that as an abrasive material, and should it find no other, this alone would be sufficient to class it as one of the most valuable of the materials used by the artisan. The use of emery and corundum in the form of wheels and special shapes, while of comparatively recent introduction, has grown to wonderful proportions. At no period in the world's history has the value of time been more highly appreciated than at the present day. Economy of time, increased output with a given amount of labor, and the resultant cheapening of production and consequent lower selling price of the article produced, are the demands of the times. This is being met by the manufacturer by the introduction of improved machinery and more efficient devices for rapid work and quick production. It is probable that the introduction of no other single tool into our factories, mills and shops, has produced so great a saving in labor as the emery wheel. I have not been able to obtain figures giving even an approximate value for the consumption of emery in the United States, and while I am, therefore, not prepared to say what it would actually amount to, I believe that it is several million dollars annually. These figures will convey some idea of the astonishing consumption of the material, but they will scarcely suggest the much greater amount that is, each year, saved in time and labor by its use. If emery has accomplished so much, "What," you will ask, "is left for carborundum to do?"

The amount it will do and save will depend wholly upon its hardness and fitness as an abrasive, over and above these qualities as manifested in emery. The statement has frequently been made by myself and others, that carborundum was equal in hardness to the diamond, while, perhaps, a greater number of persons—who are apparently in a position to know, have stated quite the contrary—that it is not as hard as the diamond. The final determination of this important question, in a manner satisfactory to all interested parties, remains to be made. My own conclusions were arrived at from what, to me, seemed positive tests, made without prejudice, the material having been used on diamond cutters' laps for the practical cutting and polishing of diamonds. The first test for diamond cutting was made by myself. A disc of iron was mounted in a fast running lathe, and the surface having been charged with fine carborundum crystals, a diamond contained in a ring was pressed against the revolving disc, and in from four to five minutes the facet, which had been presented to the disc, was found to be devoid of lustre, of a milky color and scored with lines. The second test was in a diamond-polishing establishment in New York. Here the proprietor was asked to re-polish the diamond above referred to, using, as the polishing agent, carborundum powder. The gentleman kindly consented to make the experiment, under the following conditions: A new lap, free from all diamond powder, should be used; my material would be tried first, and if successful, no charge would be made for the re-polishing, while if not successful, diamond powder would be substituted, and I should pay him $5 for his trouble. He added that in his opinion the $5 was just as good as earned. The new lap was mounted, and a workman supplied with one-half karat of carborundum powder, with which he was instructed to charge the lap and polish the lustreless facet. The diamond had, in the meantime been removed from its setting and mounted in lead, as is the practice in diamond polishing. Much to the surprise of the workman, the proprietor, and in some measure of myself, an application of the diamond to the lap for a period of twenty minutes removed all lines

from the facet and restored it to its former beauty. Since these first tests, I have, at odd times, spent many hours in watching the operation of diamond polishing with carborundum powder, in three different diamond-polishing establishments in New York City. These various tests served to prove that the hardness of carborundum was sufficient to cut diamond surfaces—removing deep lines from them and producing a fine polish—this work being done, in the opinion of some workmen, in a shorter time than could be performed with diamond powder. They also demonstrated that carborundum was not equal to diamond powder, in the first work of cutting the rough diamond and shaping the facet. Its failure to do this first work has been used, by some diamond cutters and others interested in diamonds and their commercial value, as a conclusive argument that it is not as hard as the diamond. While I do not wish to be understood as denying their statements, I am inclined to accept the proofs I have received with my own eyes, as conclusive evidence, that in the form of a very fine powder it compares favorably, in hardness and cutting qualities, to diamond powder of equal fineness, and to account for its failure when applied to the rougher work, it is necessary to take into consideration the brittleness of the crystals, this brittleness being, apparently, very much greater than in the case of the diamond crystal.

It is probable that methods will be worked out for reducing this brittleness, such for instance, as a process of annealing. This question, as to the exact place of carborundum in the scale of hardness, is, after all, one of scientific rather than commercial importance. Sufficient is now known to rate it very much above the abrasives ordinarily used, and as it is in the steel, iron, glass, porcelain and similar industries that the several million dollars worth of emery is yearly consumed, and not in diamond cutting, the question of first importance is, "Can carborundum be used with greater economy than emery?" To put the question in another form, "How will the cost of a given amount of work performed with carborundum compare with the cost of the same work done with emery?"

We will take a case of brass valve grinding; this being a case, where owing to the metal being comparatively soft, the test will favor the softer abrasive. A number of establishments are now using carborundum powder for this class of work. In one factory they formerly used a fine emery which cost them twenty cents per pound, while the carborundum powder cost them twenty times that amount, or $4.00 per pound. The experience of months has demonstrated to them, that in the hands of a good, careful workman, one-eighth of an ounce is sufficient for one day's work, and that with such a quantity the workman will perform not less than twice the amount of work that he could have done with any amount of emery.

The wages of the workmen are $2.50 per day. We here have, as the result of using one-eighth of an ounce of carborundum, costing six and one-fourth cents, an additional output amounting to the labor of one workman at $2.50, and assuming the emery to cost nothing, we have a value for the carborundum used of $2.43¾, and this without counting the value of the larger production turned out from the same machinery, floor space, etc. It must be admitted that this result is not attainable in all cases, for it is evident that a careless workmen could, and does, very materially reduce this saving by his wasteful use of the carborundum powder. This does not, however, change the relative values of the two abrasives, which we know it is possible to obtain. In glass cutting, tests that have been made, indicate that a given amount of work can be performed in one-fourth the time required when emery is used. Much the same conditions regarding time are found to exist in the case of carborundum on hard steel or chilled iron, and the sum of the results thus far obtained indicate an average saving of labor amounting to at least twenty-five per cent.

The value of the other two characteristics referred to—infusibility and incombustibility—as applied to industrial uses, it is at present impossible to determine. It was these qualities that made carborundum a material equal to and perhaps surpassing all others, from which to construct the

small buttons used in the Tesla lamps, as shown in his lecture before the Franklin Institute last February.

The crystallographic formation of carborundum is a subject that has not received any attention at my hands, nor in the works of the Carborundum Company. I am pleased to be able to state, however, that this subject has received the attention of Professors Frazer and Richards.

The specific gravity of green carborundum crystals was found by Dr. Mulhaeuser to be 3·22.

It will be probably as interesting to you as it was at first disturbing to me, to learn that a compound, responding to the formula SiC, has been produced by another without any known knowledge of my investigations. In the transactions of the Academy of Sciences of France (session of Monday, May 16, 1892), will be found a communication under the title, "Contribution to the History of Carbo-silicious Compounds," by Mr. P. Schützenberger. In his communication, Mr. Schützenberger described at length the manufacture of a new chemical compound of simple formula, the symbol being SiC. Briefly stated, his method was to enclose a mixture of silicon and silica in a bone-black crucible, the latter being securely covered with a lid of like material and embedded in lampblack contained in a larger crucible of graphite. This, again, was embedded in a third crucible, and the resulting nest was placed in a suitable furnace and brought up to, and held at, a high heat for some hours. Upon cooling and opening, the contained silicon was found to have been changed to a green substance and to have gained in weight an amount equal to one-half of its original weight, the silica remaining unchanged. An analysis showed the green material to be carbide of silicon with the formula SiC. No reference was made to the presence of crystals, and as it is probable the silicon used was a powder, the carbide was probably, also, in the same form. The disturbed state of mind—not to specify it more definitely—which I first experienced upon learning of Mr Schützenberger's work, was completely relieved when I found the date of his communication was three months later than the date on which Mr. Nikola Tesla exhibited

a lamp containing carborundum, before the assembled scientific societies of France. The composition of what I had called carborundum was not, however, known at that date. Mr. Tesla could not state what it was, nor did any one else, to my knowledge, know that it was carbide of silicon responding to the formula SiC.

APPENDIX.

REPORT OF AN EXAMINATION OF CRYSTALS FURNISHED BY MR. E. G. ACHESON, PRESIDENT OF THE CARBORUNDUM COMPANY.

The specimens examined were aggregations of crystals, the individual crystals, usually more or less disc shaped, varying in their largest dimensions from a fraction of a millimetre to about three millimetres. The faces were usually smooth with brilliant, adamantine lustre. The images reflected from them in the goniometer were frequently double or multiple, sometimes blurred, and sometimes broadened by diffraction. Occasionally, however, single, somewhat sharply defined, images were obtained.

The color of some of the crystals was a yellowish-green; that of others varied from a bluish-green to blue.

The crystals were found to be rhombohedral, their disc shape being due to the predominance of the basal pinacoid. The observed forms consisted of numerous direct and inverse rhombohedra, with the basal pinacoid and, in some crystals, the prism of the first order. The following rhombohedra were observed and determined, viz: $\frac{1}{5}$, $\frac{4}{5}$, $\frac{10}{11}$, 1, $\frac{5}{4}$, $\frac{4}{3}$, $\frac{10}{7}$, 2, $\frac{5}{2}$, 4, $\frac{10}{4}$, 5, 10. No evident marks were discovered to distinguish direct from inverse rhombohedra. In one crystal, the following grouping was observed:

Direct rhombohedra.	*Inverse rhombohedra.*
1	$\frac{10}{11}$
$\frac{10}{7}$	2
$\frac{5}{2}$	8
10	$\frac{10}{4}$
	5

In some crystals, like that just described, the rhombohedral symmetry was evident; in others, the direct and

inverse rhombohedra of the same parameters were found on the same crystal, so as to impart to it an appearance of holohedral hexagonal symmetry. This holohedral habit was observed in bluish-green and blue crystals, while in those yellowish-green crystals, which were examined in the goniometer, the habit was rhombohedral. Further investigation will be needed to decide whether this coincidence is accidental or not.

The value for the length of the vertical axis was calculated from four good measurements made on three different crystals, with the following results:

$$c = 1{\cdot}2267$$
$$1{\cdot}2261$$
$$1{\cdot}2264$$
$$1.2264$$

giving the mean value, $c = 1{\cdot}2264$.

The following are a few angles between the most frequently occurring forms observed:

	Calculated.	*Observed.*
$0 \wedge \frac{1}{10}$, ...	52° 09′ 42″	52° 07½′ to 52° 14½′
$0 \wedge 1$, ...	54° 46′ 22″	54° 43¼′ to 54° 50¼′
$0 \wedge \frac{1}{2}$, ...	60° 32′ 15″	60° 32′ to 60° 46½′
$0 \wedge \frac{9}{7}$, ...	63° 41′ 49″	63° 41½′ to 63° 43¼
$0 \wedge 2$, ...	70° 33′ 12″	70° 31′ to 70° 38′
$0 \wedge 5$, ...	74° 13′ 39″	74° 13½′ to 74° 15¾′
$0 \wedge 10$, ...	85° 57′ 39″	85° 56¾′ to 86° 02′
$1 \wedge 1$ (terminal), ...	90° 04′ 43″	
$2 \wedge 2$ (terminal), ...	109° 29′ 43″	109° 30½′

It is worthy of notice, in view of the isometric crystallization of the diamond, that the rhombohedron chosen as the unit rhombohedron has almost the shape of the cube, while the rhombohedron 2, a frequently occurring form, in combination with the basal pinacoid has very nearly the shape of the regular octahedron.

No distinct cleavage was observed.

In one instance, a twin was observed, two disc-shaped crystals being so grouped that their basal pinacoids made an angle of 109° 29′ + with each other. This would conform to the law, twinning plane, that of the unit rhombohedron.

A flat crystal examined under the microscope in converging polarized light gave the interference figure of a uniaxial mineral, thus confirming the determination of hexagonal symmetry made by measurements with the goniometer.

B. W. FRAZIER,
Professor of Mineralogy and Metallurgy, Lehigh University.
South Bethlehem, Pa., June 21, 1893.

The specific gravity of several grammes was determined by the specific gravity bottle as 3·123, at 25° C. = 60° F. When it was found that the blue crystals were apparently a di-morphic form of the green ones, a sample of each kind was put into a Sonstadt solution of sp. gr. 3·2, which was diluted down carefully until at a sp. gr. of 3·05, at which point the green crystal had sunk while the blue crystal still floated. It was thus evident that the blue variety has a lower specific gravity than the green.

JOSEPH W. RICHARDS.

ANTI-FRICTION BALL BEARINGS AND THEIR MANUFACTURE.

BY GEORGE F. SIMONDS.

[*Read at the stated meeting of the Franklin Institute, held April 19, 1893.*]

JOS. M. WILSON, President, in the chair.

MR. SIMONDS:

It was my privilege to read a paper before the members of this Institute, in June, 1888, on the "Metal Rolling Machine," and I am now pleased to bring to your attention a few facts in reference to what has been the natural outcome of that machine; anti-friction ball bearings and their manufacture.

A casual remark, heard at the Paris Exposition, in 1889, called my attention to the importance and value of ball bearings in removing friction, if they could be brought into practical use, and to make a market for the rolling machine

in the manufacture of balls, the subject was brought under consideration, with results which shall be given you to-night.

The fundamental principle on which balls are now used in bicycles is not correct, and illustrations will be given of a bicycle pedal bearing, showing the present style of ball bearing, the new double-cage ball bearing, and the new single- or bevel-cage ball bearing, also the principle of the double cage bearing as applied to heavy work. It will be observed that in the present style of bearing:

(1) The balls are loose, and must be handled singly.

(2) Each ball is required to sustain both the weight and end thrust.

(3) But two rows of balls can be used, one row at each end of the bearing.

(4) On account of the principle on which it is constructed the balls and bearing surfaces wear away.

(5) There must be a means of adjustment on account of this wear.

In the double-cage bearing these conditions are reversed. The balls are confined in cages, and readily and safely handled; one set of balls carries the weight, while another set takes the end thrust; any required number of balls can be utilized; properly made there is practically no wear, and, as there is no wear of the parts, no adjustment is necessary.

The statement that there is practically no wear to a ball bearing when designed and constructed on the correct principle, will undoubtedly be questioned, but as long use shows no change in the measurement of the size of the balls and bearing surfaces, and as the oil with which they are lubricated is not materially discolored, the claim would seem to be justified.

The bevel-cage bearing was originated to take the place of the present style of bearing for light work only, for utility, and for economy in construction. It is superior to the present style of bearing, in that the balls are carried in cages, and that they run on plane bevel surfaces in place of grooved bevel surfaces. The bevel-cage bearing will come into use where the work is very light, and where the greatest

economy in construction is necessary. The double-cage bearing will be generally adopted in those classes of vehicles and machinery where the best is wanted, and economy in use and permanency is in demand.

In subsequent remarks on the *bearings themselves*, reference is made to the double-cage bearings only, in the *manufacture* of the bearings, to both the double- and single-cage bearings.

The shafting and parts of the machinery in a small manufactory were started on these bearings in August, 1891, and have been in constant use since. Several carriages have been mounted on them, and a brougham so constructed has been on the streets of this city for the past thirty days. A street car constructed with bearings with three-eighths inch balls, after constant use for five months, sixteen hours per day, showed no wear whatever. Balls that were applied between plane surfaces under heavy pressure, measured the same at the end of four years, as when first put at work. Several bicyles, ridden constantly for two seasons, developed marked superiority over the old construction. Many instances can be cited, showing the practicability and value of the bearings.

When the proper principles for the bearings had been discovered, and the designs perfected, but a beginning had been made looking to their general introduction. A ball bearing to be of lasting commercial value must be absolutely accurate and reliable. Perfect spheres were indispensable, and they had never been commercially produced, and the balls and bearing surfaces were required to be of a temper always uniform and reliable, and by no known processes could these results be attained. A small shop was erected in which a force of skilled men have been employed for the past twenty months, and steel balls are now made of absolute sphericity, alike one with another, and with great economy, and a system has been developed for making tempered articles uniform in quality, with a great saving in cost over existing methods, for doing similar work. The accuracy and efficiency of the new system of making spheres will be appreciated when it is stated that balls one-sixth,

one thirty-second, one sixty-fourth of an inch in diameter have been ground from pieces of steel, cylindrical in form, so that they do not vary a ten-thousandth part of an inch from perfect spheres or from each other in size.

As the patents covering these various processes and devices are not yet all issued, detailed descriptions must in some cases be withheld, but enough can be made known to convey a general idea.

The new system for making tempered articles is covered by a series of patents under the following titles:

The metallurgical furnace.

The tempering oven.

The double bath hardening process.

The process for hardening rings and sleeves.

By this system Bessemer or open-hearth steel is used, carrying about ten points of carbon and costing from two cents to three cents per pound, in place of machinery or tool steel, carrying from thirty to 150 points of carbon, and costing from six to sixteen cents per pound.

That those who are not familiar with the nature of steel, and with the terms necessary to be used in this description, it should be stated that steel, no matter by what name it is known, carrying thirty-one hundredths of one per cent. of carbon or less (or thirty points, which descriptive words are now generally used) will not harden, but above that point it will harden, and the higher the percentage of carbon which the steel carries, the harder it will harden. What is known as machinery steel, carries generally less than sixty points; tool steel in general use from sixty to 100 points, and high grades or tool steel from 100 to 150 points.

The carbon in steel, as now in general use for nearly all purposes, extends through its entire structure, and the higher the carbon that may be required in steel for any given article, the more difficult, laborious and expensive it is to work it to its required shape. After an article has been brought to shape, in order to harden it, it is heated to a red heat and suddenly cooled, which makes it harder than, as a rule, it is required or desirable that it should be. It is then again heated and its temper drawn to any required degree

of softness, which temper is determined, as a rule, by the color the article assumes under the different degrees of heat to which it is subjected. This describes the ordinary process of hardening and tempering. Now, by the hardening process, the quick cooling of a tool made of high carbon steel throughout, causes warping and breaking, and has been a source of untold trouble to workers of steel for all time. It is customary in hardening, when the tool needs to be very hard, to cool the article in water or brine, which cools quickly, this secures the desired hardness, but the sudden cooling sets up unequal strains throughout the article, causing the warping and breaking. When extreme hardness is not required, or when an article cannot safely be dipped in brine, it is cooled in a slow cooling medium, like oil. This hardens to some extent and makes the article tough, and with less liability to fracture.

To largely overcome these difficulties "the double bath hardening process" was devised, by means of which the article is plunged into brine and instantly transferred into oil without coming in contact with the air. By means of this device which I now use for hardening all articles, all the advantages are gotten of both the quick and slow-cooling processes now in use, and with much less liability of fracture, and in many cases it is not necessary to afterwards draw the temper.

There have always been more or less articles made from iron or steel of low carbon and treated to the process known as case hardening. This process, as heretofore practised, has made the surface, as a rule, hard for only a slight depth; to use the expression as generally applied in this connection, "skin deep." Greater depth than this is at times secured, but with no certainty of results. By means of the furnace to which I now refer, the ancient and well-known cementation, case-hardening process is brought under complete control.

All have become familiar with the Harvey process, as applied to armor-plate. Great depth of high carbon is secured by that process in the surface of low-carbon steel, by subjecting the same, while buried in carbonaceous

material, to a high heat, beyond the melting point of cast iron. My furnace was designed and constructed with the view of adopting that process in making the bearing surfaces of these ball bearings, but on testing it, I found that the high heat necessary by the process, raised the grain of the steel, so that it was not adapted for these purposes. The high heat also, as it proved, would destroy the efficiency of my furnace, and I decided to use tool steel for the bearing surfaces and the workmen were instructed to use the furnace for annealing and case-hardening purposes. Later developments, using the ordinary process of case-hardening with the article packed in carbonaceous material in a cast-iron box, demonstrated that the furnace would accomplish, at a low heat, what had before only been possible to do at a high heat. It has taken more than a year of investigation to learn why it accomplishes this result, but this is now known.

By means of this furnace, for the past eighteen months, all the bearing surfaces for these ball bearings have been made from ten carbon Bessemer steel, and also all the reamers, taps, gauges, etc., which have been needed in their construction, as well as a large variety of articles for other purposes.

Having secured, through analysis, the exact result of each days work, it has been demonstrated that formulæ may be established, and by set rules definite and inflexible results will be obtained. The surface of any article can be carburized to any given required depth, and to any high degree of carbon, at a low heat, and in a limited time, without impairing the cutting or wearing qualities of the steel. The furnace is operated at a very moderate expense for fuel, and has needed no repairs in eighteen months of constant use. During that time no article has been cracked or broken through the processes.

By means of the new process for hardening rings and sleeves any number of tubular pieces can be hardened with absolute precision alike one with another. This is especially valuable in the manufacture of the ball bearings, but will, in time, come into general use for all purposes to which it is adapted.

The tempering oven is quite new, and will give a uniform heat for drawing the temper, which, so far as I am aware, is not at present attainable.

These ball bearings have been subjected to an exhaustive test to determine the saving in power and their wearing qualities. This test demonstrated that the friction is less than one-thirtieth of that developed by the best class of ordinary bearings as now in use. The rotating shaft of the testing machine, a machine designed and made especially for the purpose, was two and one-eighth inches in diameter, and the balls as used in the bearings were three-eighths of an inch in diameter. The first series of tests demonstrated that the maximum speed attainable with the best ordinary bearings, under 200 pounds pressure, was 1,000 revolutions per minute, owing to excessive heating of the journals and boxes. A ball bearing mounted on the same shaft at 1,000 revolutions, under a pressure of 2,800 pounds, did not heat at all.

In the second series of tests, ball bearings were introduced in the machine, where the ordinary bearing in the first test had been used. The velocity of the shaft was then increased to 2,600 revolutions per minute, and it was demonstrated that increase of pressure on the bearings did not perceptibly increase the resistance (or friction), and with an increase in the velocity, the resistance was so slight as to be of no material importance.

A test of the resisting power of steel balls was made. Three three-eighths inch balls stood a direct pressure of 175,000 pounds, or 58,000 pounds per ball without injury. The same size balls were rotated between parallel plane surfaces, and under these conditions the balls and the bearing surfaces (the latter Bessemer steel, case hardened) successfully withstood a pressure of 2,500 pounds per ball.

In conclusion, I will say that the work which I lay before you has not extended simply to establishing principles but has been carried into practical use in all its branches. Problems will arise which will need be solved, but they will not be questions of leading importance.

THE CHEMICAL SECTION

OF THE

FRANKLIN INSTITUTE.

[*Proceedings of the stated meeting, held Tuesday, September 19, 1893.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, September 19, 1893.

Dr. WM. H. GREENE, President, in the chair.

Mr. J. Benjamin Glavin, 1312 Passyunk Avenue, proposed for membership by Dr. Wahl at the June meeting, was duly elected.

Dr. Wahl also proposed the name of Mr. C. E. Martin, chemist to the house of James Martin & Co., 125 Chestnut Street. At the close of the meeting Mr. Martin was duly elected to membership.

Bills amounting to $93.20, covering items of subscriptions to journals and expenses of addressing and mailing section notices, were approved by vote and ordered to be paid.

The report of the committee appointed to prepare a memorial of the late Conrad J. Semper, was read, accepted and ordered to be spread upon the minutes. (The memorial is printed as an appendix to these minutes.)

Mr. Pemberton read an interesting and carefully prepared paper on "The Determination of Phosphoric Acid by the Titration of the Yellow Precipitate with Standard Alkali." The paper was very favorably commented upon by Dr. Terne and briefly discussed by him and the author.

Professor Smith followed with a paper on "The Atomic Weight of Molybdenum," prepared jointly by himself and Mr. Philip Maas. It was discussed by Mr. R. A. Fisher, the President, and the author. Both papers were referred for publication in the *Journal*.

The meeting then adjourned. WM. C. DAY, *Secretary*.

CONRAD J. SEMPER.

In the death of Conrad J. Semper, which occurred on June 12, 1893, the Chemical Section has suffered the loss of one of its estimable members, who, though his name does not appear as a contributor to the published volumes of its proceedings, was nevertheless a frequent attendant of its meetings and always exhibited a lively interest in its welfare.

Mr. Semper was a son of Gottfried Semper, a distinguished architect, and received his early education at the Polytechnic School at Zürich, completing his studies in chemistry in Berlin, Freiberg, Tübingen and Heidelberg.

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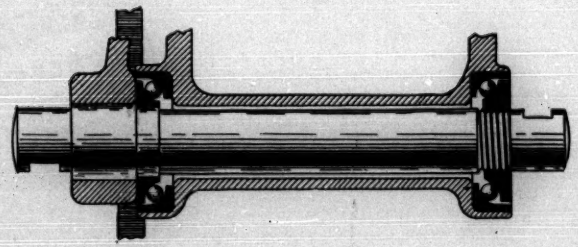

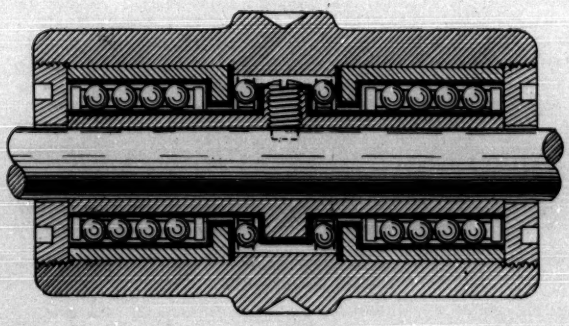

SIMONDS' IMPROVEMENTS IN

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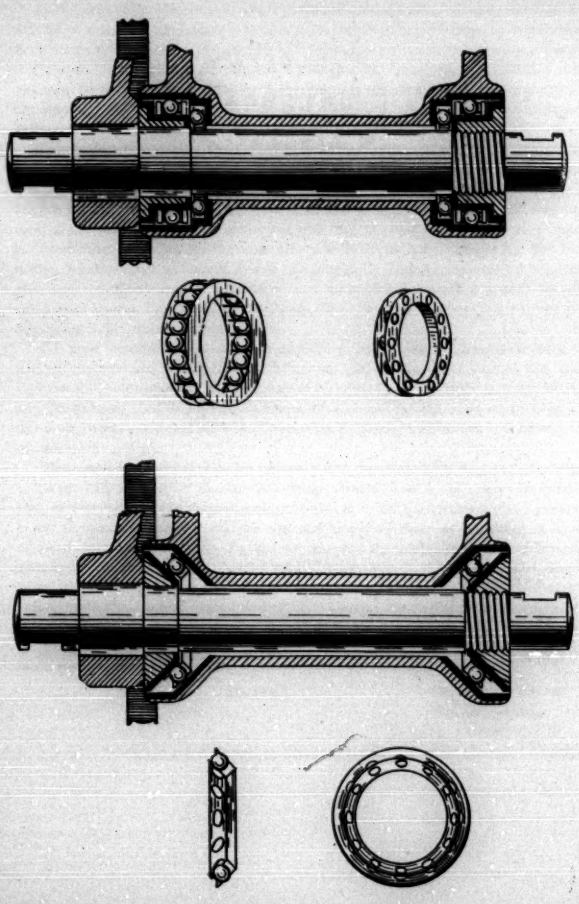

ANTI-FRICTION BALL BEARINGS.

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In the year 1865, Harrison Brothers & Co., of Philadelphia, being in need of the services of a chemist conversant with a certain branch of manufacture in which they were interested, requested their agents in Germany to aid them in securing a competent person. Through these gentlemen the request was conveyed to Dr. Zürich, who was then Director of the Laboratory of the Prussian Government, and who suggested his assistant, Mr. Semper, for the position. This suggestion resulted in Semper's engagement by the firm.

This engagement proved to be a permanent one, and was fulfilled with such mutual satisfaction that Semper, in due course, became the chemical manager of the house, which post he continued to occupy until his death.

His professional work was naturally confined to the development and improvement of methods and processes connected with the business of manufacturing chemicals and colors, in which the house of Harrison Brothers & Co. occupy the first rank among American manufacturers, and to this congenial work he directed all his energies, and, though no serious contributions to professional literature appear to have come from his pen, the records of the Patent Office bear testimony to his activity and originality in his chosen sphere of work.

His most important technical work appears to have been in connection with the study of the treatment of beauxite for the commercial production of alumina salts especially in the development of the reactions of metallic dioxides (such as those of lead and manganese) upon ferruginous solutions of alumina, for the removal of iron. In this work he was associated with Dr. Constantine Fahlberg, well-known as the discoverer of saccharin.

The house, in whose service his life was spent, bears the following warm testimony to his professional skill: "The late Mr. Semper was without doubt a very able chemist, and, when occasion required, showed great genius. His attention was given generally to our various manufactures, and we regarded him at all times as the fountain source of our chemical knowledge." To this we may add the cordial testimony of his business and professional friends, that his excellent judgment in the planning and erection of buildings and apparatus, and his great experience and eminently practical turn of mind, made him a sound adviser and capable director, whose place it will be difficult to fill.

Personally, Mr. Semper was most amiable in disposition and endeared himself to a wide circle of friends. A widow and three sons survive him.

[SIGNED] DR. BRUNO TERNE,
WM. H. WAHL,
H. PEMBERTON, JR.

ARTESIAN WELLS.

By Oscar C. S. Carter.
Professor of Geology and Mineralogy, Central High School, Philadelphia.

[*Read at the stated meeting of the Chemical Section, held March 21, 1893.*]

[*Continued from p. 239.*]

Deep Artesian Well in the Mica Schist of Philadelphia.—This well was drilled at the Gladstone Hotel, Eleventh and Pine Streets, to obtain water for drinking and household purposes. This well, at the time of writing, December, 1892, is not finished. The present depth of the well is 576 feet; the first forty-four feet passed through was clay and gravel, then the usual mica schist rock was struck. No drillings were preserved, but two specimens of rock broken off by the drill were kept, one at a depth of ninety feet, the other at a depth of 240 feet. The first specimen proved to be hornblende crystallized; the second specimen was mica schist, composed of biotite mica, feldspar and large grains of transparent quartz. I am doubtful about the depth of the first specimen, and think it must have come from a much greater depth than ninety feet, assigned by the driller because no hornblende was seen in any of the pumpings of the well drilled by the Oriental Bath Company, of 1104 Walnut Street. This well was 265 feet in depth, and the drillings were carefully preserved for about every ten feet. The second specimen corresponds with the rock found at nearly the same depth at the Walnut Street well. The first specimen was a mass of a pure hornblende, and may be regarded as an accessory mineral of the mica schist rock, and not as hornblende schist. The well yields 5,100 gallons per hour, and with an improved pump will give over 6,000 gallons per hour. The water rises to within thirty-one feet of the surface, which corresponds closely with the Green Street and Walnut Street wells. On pumping forty-eight hours, or 244,800 gallons, the water falls from the height of thirty-one to fifty-one feet, or a drop of twenty feet in forty-

eight hours, It remains at fifty-one feet from the surface no matter how long it is pumped.

Deep Artesian Wells in the Mica Schist at Jenkintown.—The two wells at Jenkintown were drilled for the purpose of supplying drinking water to the town, and also the surrounding country for a distance of three miles; in this they were eminently successful.

The present depth of the first well is 324 feet; of the second well, 349 feet. They are only eight feet apart. They are both cased for a distance of forty-five feet with iron pipe. The two wells at present are connected. The second well was at first only 270 feet deep, but was afterwards drilled to a depth of 349 feet. On deepening this well they struck at 310 feet a fissure or crevice, which connects the two wells. Before the wells were connected, the water rose to within thirty-eight feet of the surface in the first well, and within sixty feet of the surface in the second. At present they both stand at the same level. The wells yield 9,000 gallons each per hour, and by constant pumping for fifteen hours the fall is 150 feet.

Artesian Well in the Mica Schist of Philadelphia.—This well was drilled at the northwest corner of Twenty-fourth and Green Streets, to obtain water for the manufacture of artificial ice. The well is eight inches in diameter and was drilled to a depth of 300 feet. The well was cased with iron pipe to a depth of thirty feet and afterwards to sixty feet, but it is the intention of the company to case it to a depth of 120 feet.

The water rises to within twenty-six feet of the surface. At the well drilled by the Oriental Bath Company, of 1104 Walnut Street, the water rises to within twenty-eight feet of the surface. The Green Street well yields about 5,160 gallons per hour, while the Walnut Street well yields 6,000 gallons per hour.

The drillings of the Green Street well were not preserved.

The Montgomery County wells are nearly all six inches in diameter and when lined with iron pipe they are five and five-eighths inches in diameter.

The motive-power is a twelve horse-power engine. The beam is fifteen feet in length, the drill bar three inches in diameter. The drill has a drop of eighteen inches.

Artesian Well in the Trias at Norristown, Pa.—This well was drilled on the top of Sandy Hill, a very high hill which overlooks Norristown and the Schuylkill Valley. The drilling was commenced in the bottom of an old dry well, fifty feet in depth, on the property of John T. Dyer.

56—Sandstone,	to	56
6—Dark red shale,	"	62
6—Red shale micaceous,		68
2—Sandstone, light colored transparent quartz, abundance of silvery muscovite,		70
5—Red shale,		75
5—White sandstone muscovite, quartz and pink orthoclase,		80
2—Same,		82
2—Pink sandstone, more pink orthoclase,		84
2—White sandstone, finer grained,		86
5—White sandstone orthoclase, quartz, very little mica,		91
4—Red shale, no mica,		95
5—Red shale, slightly micaceous,		100
2—Red sandstone, fine grained,		102
2—Gray sandstone, little mica,		104
8—Light red sandstone, orthoclase, quartz and muscovite,		112
2—White sandstone, feldspathic,		114
2—Red shale,		116
9—Red sandstone, feldspathic,		125
5—White sandstone, very fine grained, little mica, feldspar missing,		130
5—Dark red sandstone, micaceous,		135
5—Dark red sandstone, slightly micaceous,		140
5—White sandstone like 130, resembles sea sand,		145
5—White sandstone, very fine grained, only little feldspar,		150
10—Pink and white sandstone, orthoclase and muscovite,		160
9—Pink and white sandstone, muscovite and more orthoclase,		169

Very few water crevices were met with, the first crevice was at a depth of seventy-four feet, no water was struck again until a depth of 167 feet was reached. The well was tested when a depth of 121 feet was reached, and was pumped dry in seven minutes, this water mostly came from the first crevice at seventy-four feet. When the depth of 169 feet was reached the well was again tested and yielded

900 gallons per hour, after four hours' steady pumping the water did not lower.

The water rises in the well to within seventy-four feet of the surface. This is rather remarkable when we consider that the hill is a steep one and the well is within a short distance of the slope; many predicted that little water would be found on such a high hill.

Artesian Well in the Silurian Limestone near Lancasterville, Montgomery County, Pa.—This well was drilled on the property of H. F. Hallman. The drilling was commenced in an old well, which was already sixty-four feet in depth.

64 feet	to	64
11—Limestone,	"	75
4—Blue limestone,		79
6—Gray limestone,		85
9—White limestone,		94
2—White limestone, slightly micaceous,		96
2—Gray limestone, slightly micaceous and silicious,		98

Crevices were met with at seventy-nine feet, and four or five between eighty-five and ninety-four feet. The rock was very loose, and the water rises to within sixty-four feet of the surface. The well yields 600 gallons per hour, after five hours' continuous pumping the level does not lower any.

Artesian Well in the Trias Red Shale, Jeffersonville, Montgomery County, Pa.—This well was drilled on the property of of F. A. Poth, and passed through a bed of red shale, forty-six feet in thickness.

10—Clay,	to	10
5—Sandstone,		15
15—Gray sandstone, feldspathic,		30
10—Same,		40
5—Red shale, micaceous,		45
5—Red shale, coarser, more mica,		50
5—Red shale, lighter color, little mica,		55
14—Red shale, very dark in color, much red hematite,		69
6—Red shale, softer micaceous,		75
11—Red shale, dark red, fine grained, micaceous,		86
6½—Sandstone, gray feldspathic, micaceous,		92½

This well was not tested by the drillers, but Mr. Poth put down a deep well steam pump with a capacity of thirty

gallons per minute. It is the opinion of the driller that the well yields twenty gallons per minute. Water was first struck between thirty-five and forty feet, and small crevices were met with below this.

Artesian Well in Trias between Norristown and Jeffersonville.—Well drilled on the property of the West End Land Company, about two miles from the Trenton limestone, which outcrops at Mogee's Station, along the Schuylkill.

10—Yellow sandstone, crumbling,	to	10
10—Same,		20
10—Red shale, micaceous,		30
7—Red sandstone, micaceous,		37
11—Brown sandstone, micaceous,		48
3—Gray sandstone, much gray feldspar, some mica,		51
2—Gray sandstone, fine grained, micaceous and feldspathic,		53
22—Red sandstone, micaceous and feldspathic,		75

The well yields 1,500 gallons per hour, and does not lower after four hours' pumping.

This well was about two weeks in drilling.

Artesian Well in the Trias Hickorytown, Montgomery County:

5—Clay,	to	5
5—Decomposed sandstone,		10
30—Light yellow sandstone,		40
30—Yellow sandstone feldspathic (orthoclase),		70

Below seventy feet is a bed of white sandstone, containing muscovite and orthoclase. Water was first struck at fifty-six feet. The well yields 600 gallons per hour and the water rises to within forty-five feet of the surface.

Artesian Well in the Lowest Trias at Bridgeport, Montgomery County.—This well was drilled in the sandstone not far from the Silurian limestone of the Chester Valley, on the property of Chas. Meyers.

4—Clay,	to	4
21—Sandstone (decomposed),		25
6—Sandstone, coarse grained, light color, trace of mica,		31
9—Red shale, rich in Fe_2O_3,		40
12—Sandstone, light color, transparent quartz, slightly micaceous,		52
13—Sandstone, fine grained, micaceous,		65

The well yields 600 gallons per hour, and after pumping five hours does not lower any.

Artesian Well in the Potsdam Sandstone near Fort Washington.—This well was drilled on the property of J. Conrad, on the Bethlehem Pike, one-half mile from Fort Washington, near the site of Washington's old fort. The rock dipped steeply and it was difficult to keep the well straight.

1½—Soil,	to	1½
13½—Potsdam sandstone, coarse grained, fawn colored,	"	15
15—Potsdam sandstone, fine grained, fawn colored,	"	30
22—Potsdam sandstone, fine, slightly micaceous, darker colored,	"	52
4—Potsdam sandstone, fine, slightly micaceous, fawn colored,	"	56
8—Potsdam sandstone, fine grained, slate colored,	"	64

Water was first struck at depth of fifty-two feet and rose ten feet in the well. The well yields 600 gallons per hour, and on pumping five hours does not lower any.

Artesian Well in the Trias, Sandy Hill School House, Whitpain Township.—

6½—Sand,	to	6½
6½—Sandstone,		13
7—White sandstone, decomposed orthoclase,		20
13—Same, no mica,		33
2—Same,		35
5—Gray sandstone, some clay,		40
10—Red shale,		50
4—White sandstone, highly feldspathic,		54
4—Sandstone and clay, lead colored, micaceous,		58
2—Decomposed shale (clayey),		60

Water first struck at forty feet. The rock changes without any crevices until between fifty-four and sixty feet, when a little more water enters the well. The water rises to within twenty-eight feet of the surface. The well can be pumped dry in thirty minutes on pumping five gallons per minute. It will only yield two gallons per minute without lowering, according to the driller.

Artesian Well at Shady Grove School House, near Skippack Pike, and Morris Road, in the Trias.—

1½—Soil,	to	1½
3½—Decomposed sandstone,	"	5
5—Sandstone, coarse grained, light color (conglomerate),		10
8—Sandstone, finer grained, feldspathic, slightly micaceous,		18

6—Sandstone, coarse, highly feldspathic, much decomposed,		24
6—Same,		30
5—Red clay, derived from feldspar,		35
5—Red shale, slightly micaceous,		40
5—Red clay,		45

This well was about four days in drilling. The rock was very open from fifteen to twenty feet and it was difficult to keep any water in the well and there were small crevices in almost every change of rock, but they did not yield water. Water was first struck at twenty-four feet and rose to within nineteen feet of the surface. The well yields 900 gallons per hour and on pumping three hours and twenty minutes does not lower any.

Artesian Well in the Silurian Limestone, near Williams Station, Plymouth Railroad.—This well was drilled on the property of Thomas Phipps.

11—Soil and clay,	to	11
2—Limestone,		13
7—Limestone, coarse, yellow,		20
10—Same,		30
13—Same,		43

Struck water at sixteen feet. The rock was very loose and kept dropping in the well until harder rock was reached at twenty feet. It was necessary to case with iron pipe to twenty-three. Three crevices were met with from twenty feet to forty-three feet. The water stands at sixteen feet from the surface. The well yields 900 gallons per hour and does not lower on pumping four hours. This limestone is highly magnesian, and on analysis I find it contains a little strontium.

Water Well Drilled in the Trias, at Washington Square School House, Montgomery County.—

3—Soil,	to	3
4—Sandstone,	"	7
7—Fine grained, red shale, micaceous,	"	14
5—Coarse red shale, micaceous,		19
9—Sandstone, very coarse, mica and feldspar,		28
10½—Red clay,		38½

Below thirty-eight and one-half is a bed of red shale. First crevice was met at a depth of twenty-five feet and the

water rose to within fourteen feet of the surface. The well yields 600 gallons per hour and on pumping four hours the water does not lower any. The red clay probably holds the water.

Water Well Drilled in the Trias, at Belfry, Stony Creek Railroad.—This well was drilled at St. John's Lutheran Church.

10—Red shale,	to	10
10—Red shale, deep color, little mica, much Fe_2O_3,	"	20
5—Red shale, lighter color, finer grained, less micaceous,	"	25
5—Brown shale, hard, fine scales of mica in abundance,	"	30
2—Sandstone, brownish, gray, micaceous,	"	32
5—Sandstone, brown,	"	37

This shallow well yields only thirty gallons per hour; 100 gallons per hour would pump it dry. The water rises to within fifteen feet of the surface. Only one small water crevice was struck and that was at twenty feet. The drillers abandoned this well; the reason it was not finished was because it was impossible to keep the well straight. It started to go crooked at twenty-two feet and continued so all the way down. Every method known to the drillers was tried, but it was impossible to keep it straight. The water was a little hard. No charge was made for drilling.

The CHLORIDE ELECTRICAL STORAGE BATTERY.

By Herbert Lloyd, F.C.S.

[*Read at the meeting of the Electrical Section, Tuesday, Sept. 26, 1893.*]

The electrical accumulator which I will try to describe is known as the chloride cell. It is so called because the plates constituting the element are made up of tablets cast from fused chlorides of lead and zinc, held together by a frame or rim of antimonious lead. When these composite plates are cast, however, they are not capable of use in a storage battery. They do not contain material which is in any sense active material, nor material capable of becoming active in a secondary battery fluid. They are not capable of serving as oxygen plates, as they will not absorb oxygen, nor are they capable of use as hydrogen plates, as not only would their immersion in the dilute sulphuric acid of the storage battery result in contaminating the fluid with chloride of zinc, which would be fatal to its proper action as a storage battery fluid, but the effect of the hydrogen liberated would be to form hydrochloric acid, with the chlorine of the chloride of lead, which hydrochloric acid would further contaminate the fluid and make it inoperative as a storage battery fluid. Moreover, these tablets are non-conductors of electricity. It is plain, therefore, that a plate consisting of tablets of chloride of lead and chloride of zinc is worthless as a storage battery plate, and cannot be used as such. Its chemical composition must first be radically changed to fit it for use either as an oxygen plate or a hydrogen plate.

This chemical change is brought about by means of a bath of chloride of zinc or some equivalent substance, in which the plate of tablets is to be immersed in connection with a slab of metallic zinc. This arrangement is, in fact, a primary battery, in which the zinc acts as the positive element, while the tablets constitute the negative element.

This operation may be performed with current produced

by a dynamo, but it is a very tedious and expensive process as compared with reduction by means of zinc.

The electro-chemical action in this combination results in withdrawing the chloride of zinc from the tablets by simple solution in the bath, and the withdrawal of the chlorine of the chloride of lead from the tablets and fixing it in combination with the zinc with the formation of chloride of zinc. It may, therefore, be said that the chloride of lead tablets constitute material which is destined to become active by electrical disintegration, which is brought about when they are connected with the zinc plates in the bath of chloride of zinc.

When this process of electrical disintegration is complete, and the chloride of zinc is washed out of the plate, a mass of crystallized metallic lead is left, which is suitable for immediate use in a storage battery, without the tedious forming process of Planté and without the application of any active material or material about to become active by the processes of Brush and Faure.

To describe in detail the process used in the manufacture of this plate, as it is carried on commercially, I will begin with metallic lead. The first step in the production of chloride of lead is to bring the lead into such a state of subdivision as to make it readily soluble in nitric acid. The old way of doing this was to pour molten lead into water and so granulate it, but a process which is more satisfactory is to melt the pigs of lead in a suitable furnace, and when the lead is brought to a high state of fusion to convey it through a pipe into closed chamber where it is delivered in a fine stream into a jet of dry steam, the result being that the lead is blown into a moderately fine powder and falls on the floor of the chamber. [Sample shown.]

This powder is then shovelled into earthenware baskets suspended in large tanks of dilute nitric acid. When the lead has gone into solution in the form of nitrate of lead, the clear nitrate of lead solution is run off into precipitating tanks, where, on the addition of hydrochloric acid the chloride of lead is thrown down in a fine white powder, nitric acid being set free. This nitric acid is returned to the dis-

solving pots to be used there again in bringing fresh lead into solution. The precipitated chloride is then washed by decantation and thoroughly dried.

The next step is to mix the chloride of lead so produced with the proper proportion of chloride of zinc, when both are melted together. I will show later on the direct effect produced by the chloride of zinc in the plate.

The fused chlorides are next cast into tablets [samples shown] of any desired size or shape, and with a beveled or V-shaped edge as shown. These tablets are then placed in a second mould, called a framing mould, where they are placed at a fixed distance apart to allow the frame of antimonious lead to be cast around them. In this operation, the result most desirable to obtain is to produce this framing lead in as dense a form as possible, so that unlike the material destined to become active it will not be attacked by the oxidizing current when set up in a cell. The ordinary method of casting storage battery grids is, of course, to pour the molten lead into the mould from an ordinary ladle. We have improved upon this method by forcing the molten alloy around the tablets under heavy pressure, with the result of not only forming a dense metallic frame, but also of making a very perfect contact between the pastille and the frame. The pastille, at the same time, on account of its peculiar form is dove-tailed, as it were, into the frame. This form obviates the trouble so noticeable with the ordinary red lead plate, in which the grid is dove-tailed into the plug; that is, the surface of the plug on each side of the plate is of a larger area than the centre of the plug, so that the tendency is for the plug to split in the centre and fall out on either side.

When the completed plate is taken from the framing mould it is placed in the reducing tank in connection with a plate of zinc, as described in the first instance. This reduction process extends over a period varying from twelve to twenty-four hours, according to circumstances.

When reduction is complete, the plate is thoroughly washed in running water. In order to be sure that the very least trace of chlorine has been removed from the plate, all

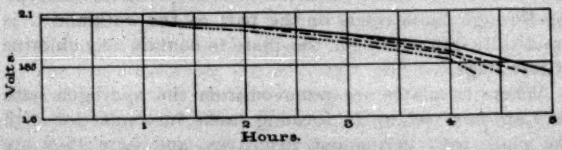
plates are set up as cathodes in a bath of dilute sulphuric acid, plain lead plates being used as permanent anodes in this tank, and a heavy current is passed through the plates for several hours. If the reduction has been incomplete the chlorine will make itself felt in this operation. Excepting through carelessness on the part of the workmen it is practically impossible for the plate to contain any chlorine at this stage.

When the plates are removed from the hydrogen bath they are next set up in forming tanks in connection with the plain lead permanent negatives, and here they are charged continuously for several weeks, or until the crystalline, spongy lead has been completely converted into peroxide of lead. The theoretical amount of current necessary to form a pound of peroxide of lead is about 200 ampère hours, and owing to the beautifully porous structure of the plate this figure holds out very well in practice; the plates will always be found thoroughly peroxidized after they have received a little over the theoretical quantity of current necessary.

The positive plates after formation are then set up with the requisite number of negative plates (the active material of which is in a soft, spongy state as it came from the reducing tank), the lugs or terminals of the plates of each series being burned together with a hydrogen flame, after being insulated in the manner shown in the sample. The cells are then charged and discharged a few times until they give their proper capacity, when they are ready for shipment.

Chloride of zinc is used in this plate for two reasons. In the first place, it is impossible to cast plates of chloride of lead without it, as the casting, on cooling falls to pieces, so the admixture of chloride of zinc is absolutely necessary on that account. In the next place, it will be readily seen that by the use of chloride of zinc it is possible to so control the density of the plate as to produce any porosity that may be desired, and as within certain limits the capacity of a plate is proportional to the porosity, this use of chloride of zinc is of vast importance. The accom-

panying curves show how the capacity of four cells of equal size and weight vary, owing to the different percentage of chloride of zinc which the plates contained when they were cast.



In the manufacture of the ordinary red lead or pasted plate, the density of the material depends mainly upon the energy which the boy uses in pushing the red lead into the grid, and consequently the plates are seldom or ever uniform. In the chloride cell, providing the materials are properly weighed and the mixture thoroughly stirred after fusion, the plates are essentially uniform, as the mixed chlorides become perfectly fluid and every plate cast is exactly like every other plate. It is never necessary to reject any plate for want of capacity.

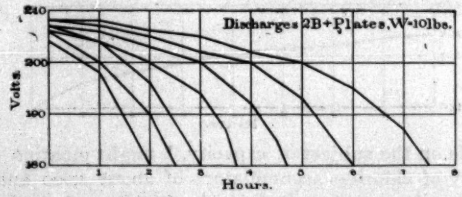
The mixed chlorides on cooling crystallize into a hard, stony substance of a peculiar crystalline nature. After reduction the metallic lead is left in the form of fine acicular crystals, running through the plate perpendicular to its surface, and the elimination of the chlorine and the chloride of zinc provides minute cell spaces around these crystals, so that an immense surface is offered for the absorption of oxygen in the forming process.

Having arrived at the proper amount of chloride of zinc to use, there is no danger of buckling or warping of the plates from undue expansion, as this expansion can be accurately provided for in the tablets.

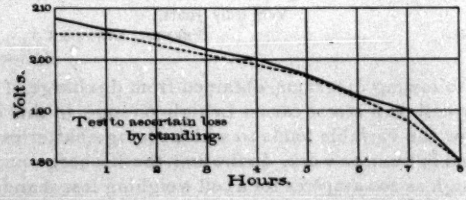
The capacity of cells of this type is from five to six ampère hours per pound of plate. The capacity for weight could be materially increased, but at the loss of durability.

At a discharge rate equal to one-half an ampère for each pound of plate, which is a higher rate than is recommended for any other lead element, this capacity of between five

and six ampère hours per pound can be obtained. At this rate of discharge the efficiency of the cell will be very high, the loss in current being less than ten per cent. and the watt-hour efficiency from seventy-five to eighty-five per cent.

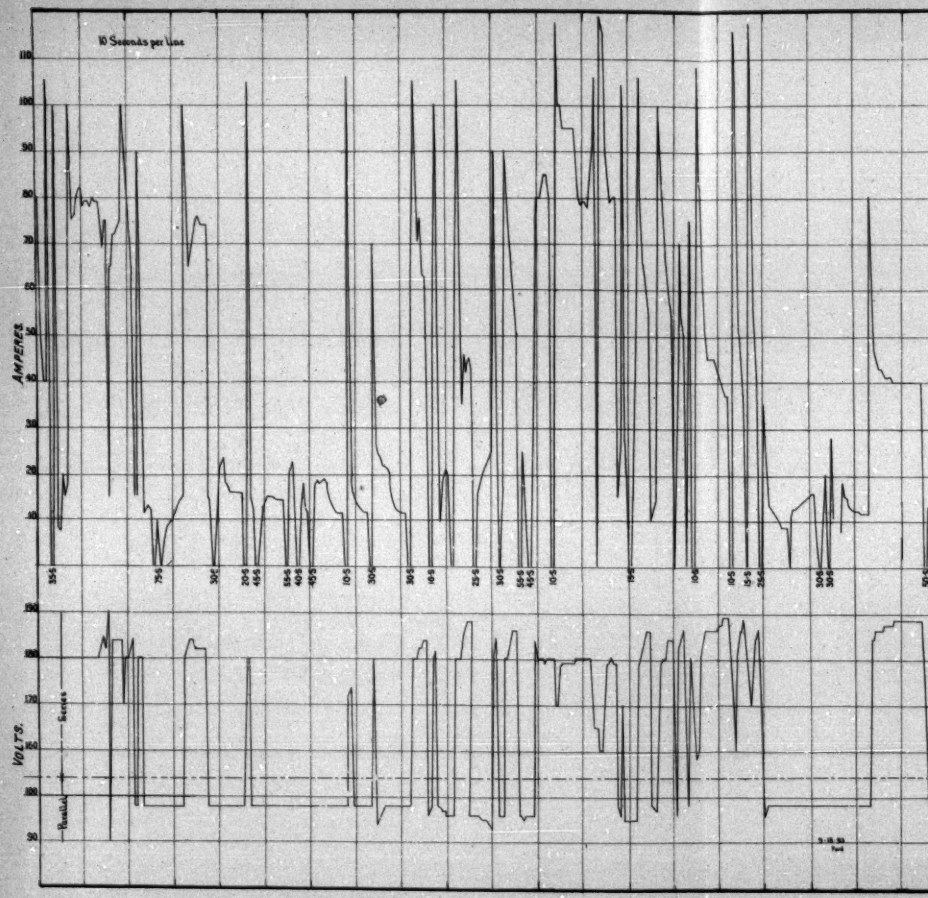


The accompanying set of curves will show the decrease in capacity as the rate is increased. The discharge rate in each of these discharges is above the normal, the lowest discharge being at the rate of three-fourths ampère per pound of plate, and the highest being at the rate of two ampères per pound of plate, or 100 ampères for an ordinary fifty-pound cell, increasing the rate 250 per cent., decreased capacity but thirty-three per cent.



Another set of curves which may be of interest is one showing the effect of allowing a cell to stand charged, the upper curve showing discharge taken immediately after charge, the lower one after the same cell had been allowed to stand charged twenty-four hours. The yield in ampère hours was the same in both cases, but there was a loss in watt hours on standing.

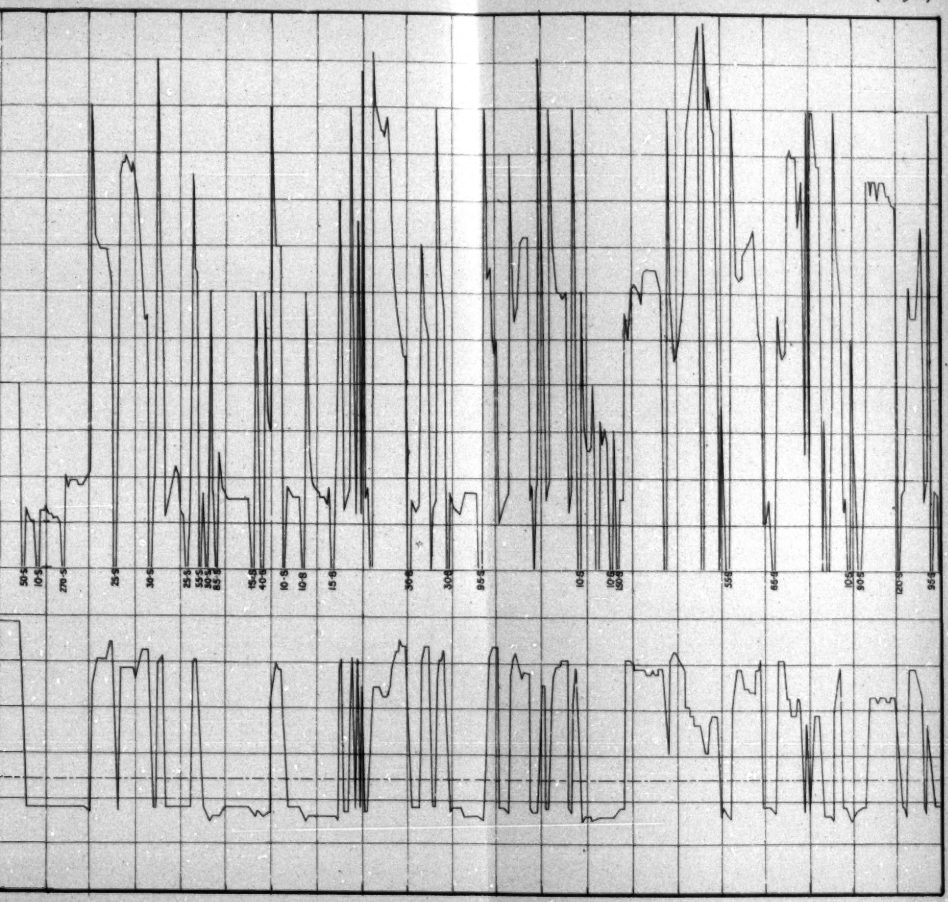
The next curve shows the discharge of a cell at a rate of two-thirds ampère per pound, when it will be seen that



DIAGRAM, SHOWING DISCHARGE OF 96 CHLORIDE CELLS,

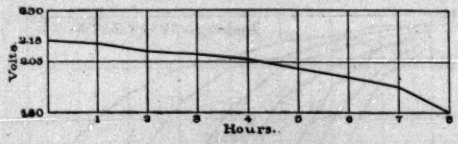
WASHIN

(*Lloyd.*)



LS, DURING 12-MILE TRIP, ON CAR OF METROPOLITAN R. R. CO.,
INGTON, D. C.

over two-thirds of the capacity was obtained above two volts. At the rate of one-half ampère per pound, over three-fourths of the capacity can be obtained above two volts. This is, in my opinion, a very desirable feature.



While on the subject of capacity, I might mention that a battery of chloride accumulators of about 2,000 ampère hours capacity was installed in the building of the Provident Life and Trust Company, Fourth and Chestnut Streets, in December, 1892. The following letter from the architects, who had the awarding of the contract, speaks for itself:

> In regard to the storage battery which you have installed in the Provident building, we would say in the test the battery delivered 1,894 ampère hours, and when the discharge was stopped, as there was still a surplus of five volts, it was evident that the battery was far from being exhausted.
>
> Considering that your guarantee was exceeded by over forty-eight per cent., it certainly speaks very highly for the battery, and is very satisfactory.
>
> Very truly yours,
>
> [SIGNED] FURNESS, EVANS & CO.,
> *Architects.*

The following diagrams, obtained from discharge of the chloride cell on a street car on Lehigh Avenue, in this city, will show the variable loads to which storage batteries are subjected in traction work. In the first, the discharge current ran as high as 200 ampères for a cell weighing less than forty pounds; in the second, over the same road, the current did not pass 100 ampères. One hundred and four cells in series.

The next diagram shows a discharge obtained from a battery of ninety-six cells of the type here shown, on the road of the Metropolitan Company, Washington, D. C. The load in this case was perhaps less than average, the tracks at the same time being in fairly good condition. The trip was about twelve miles, and several five and one-half per cent. grades were encountered, and over fifty curves.

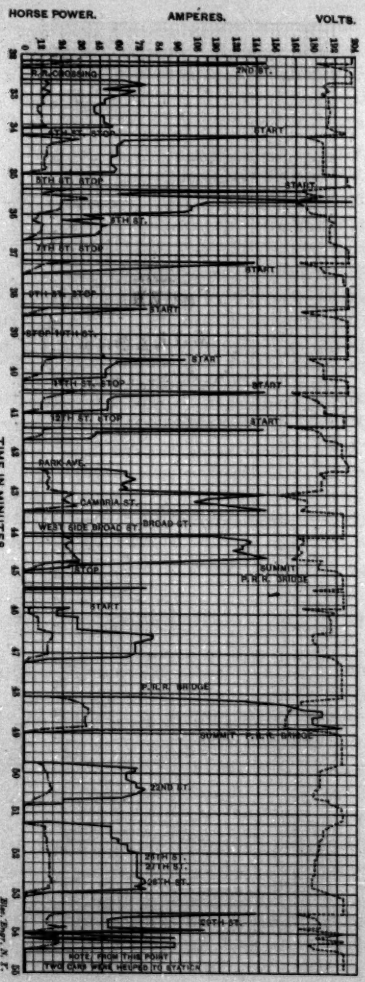


Diagram showing variations in load—Lehigh Avenue Railway, Philadelphia.

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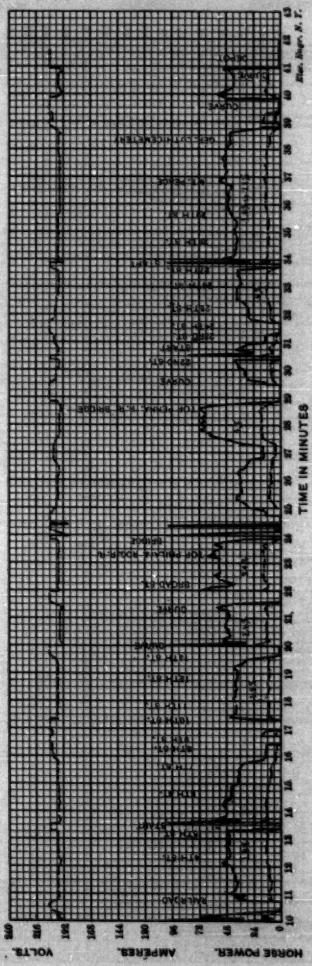


Diagram showing variations in load—Lehigh Avenue Railway, Philadelphia.

A more recent curve, taken after the cells had been in use five months, shows an improvement over this one in voltage.

An examination of the complete element will show the special care that has been given to the insulation of the plates. It is well known that the liability of a storage battery to short-circuit has been one of the main causes of trouble. To overcome this, we envelop the positive plate in a piece of beautifully woven asbestos cloth. Between this positive so protected and the negative plate we place a perforated, grooved board of insulating material, the perforations in this board being made opposite the pieces of active material in both plates, leaving free circulation of the electrolyte between the plates, at the same time keeping the asbestos cloth pressed against the face of the positive plate, causing it to form a tight covering over the face of the active material, and while making the plate absolutely safe from short-circuit, it also adds very wonderfully to the life of the cell, since the peroxide is held in position where it can perform useful work instead of being deposited on the bottom of the cell. The channels in the board provide for the free circulation of the electrolyte, and also allow for the escape of the gases. In traction work this form of insulation is found very beneficial, as the cell is vastly more durable than anything that has been before produced and at the same time there is no unnecessary liquid to be spilled over the car.

It may be of interest to state that the company manufacturing this type of cell in France has supplied batteries for nearly two years to the North Paris Tramway Company, who operate two or three roads with battery cars, about forty cars in all, I believe. I was on these cars about a year ago, and they certainly were doing good work. The cars are about twenty-two feet long, and have seats on the roof, having seating room for fifty-four passengers.

The Paris factory has for some years turned out over five tons of plates a day. They equipped the Popp stations in Paris with these accumulators some three years ago, which have been in constant use ever since. There are twenty-four sub-stations all charged in series, the lighting being done entirely from the batteries, there being two sets

in each station, one being discharged, while the other one is charged. There are in the neighborhood of 100,000 lamps run daily from these cells, the result obtained being very satisfactory, since, in addition to the benefit derived from the batteries as a store, they also act as transformers, as the batteries are charged in a 3,000-volt circuit, each station turning out current to its immediate vicinity at 110 volts. The plates in some of these cells weigh 100 pounds each, the complete cell weighing over a ton, and discharging at a rate of from 1,000 to 2,000 ampères each.

A company has recently been formed in England, for manufacturing these cells, which has just completed works near Manchester, capable of a very large output. That company is controlled by Messrs. Mather & Platt, probably the largest electrical engineers in Great Britain, and the business is to be managed by Dr. Hopkinson. Under such management there can be very little doubt about the success of the business.

The demand for storage battery in Europe is very great. European manufacturing companies, therefore, are not compelled to educate the public into their use.

BOOK NOTICES.

Theory of Structures and Strength of Materials, with Diagrams, Illustrations and Examples. By Henry T. Bovey, M.A., D.C.L., F.R.S.C., Professor of Civil Engineering and Applied Mechanics, M'Gill University, Montreal, etc. New York: John Wiley & Sons. 1893.

Emerson complains of a preacher he once heard, who "had no one word intimating that he had laughed or wept, was married or in love, had been commended, or cheated, or chagrined."

Considering that the Concord Sage is himself rather non-committal respecting these interesting questions connected with his own personality, it would no doubt be unreasonable to expect authors of works upon the theory of structures to inform their readers as to their experience in these respects, and certainly such disclosures by them would be absurdly out of place and undesirable; and yet, as we turn the pages of such volumes as the present one, and contemplate the icy hardness of their style, we are tempted to wonder whether, even in such works, an infusion of somewhat of the author's personality, an occasional intimation of the man behind the printed page, might not render the works even more useful than they are—might not act as mortar to the dry wall, or butter to the dry bread, awakening, intensifying and sustaining the student's interest in the subject, and rendering a part of

him what otherwise may too often be a dry recital of facts and propositions enunciated, and perhaps comprehended, only to be speedily forgotten.

But whether this remark be in order or otherwise, it is not to be taken as referring especially to the work before us, the author of which simply conforms to the established practice of writers of his class. Indeed, his assurance, in the preface, that the examples given are selected for the most part from his own experience, must be taken as a concession to the sentiment here expressed.

The work is a very scholarly, concise and thorough-going exposition of the subjects embraced in its title. Indeed, its scope is made to include matters not usually regarded as pertaining to these subjects, such as dynamics and some of its applications to machinery, the laws of friction as pertaining to journals, pivots, belts, ropes and pulleys, the operation of dynamometers and that of toothed gearing.

Beginning with the simplest possible frame, that of two members, the theory of stresses in more complicated frames is elaborated in Chapter I, largely with the aid of graphic methods, the application of which to the finding of centres of gravity and moments of inertia is also touched upon.

Chapter II deals with the shearing forces and bending moments in solid beams, and somewhat startles the reader at the outset by defining a beam as "a bar of somewhat considerable scantling, supported—," etc.

Chapter III has the rather unfortunate title, "Definitions and General Principles," leading the reader to suppose that the author has carelessly placed here the chapter which should have headed the work; whereas, in fact, the author at this point passes from the action of external to that of internal forces, and proceeds to a discussion of *their* "definitions and general principles."

Under sub-heading (2), "Stresses and Strains," on p. 141, five kinds of stresses are enumerated; but, although deformation is briefly referred to, it is not intimated until in the next paragraph that it is this to which the word "strain" is applied; an application which, although sanctioned by the highest authority and in conformity with present usage, we venture to regard as unfortunate.

This chapter naturally deals with Wöhler's law (referring to it as manifestly incomplete, inasmuch as it fails to take account of the influence due to rapidity of application of load, to the rate of increase of stress and to the duration of individual strains) and with Launhardt's and Weyrauch's efforts to formulate that law; while Tresca's discoveries relating to the flow of solids are briefly described. The remainder of the chapter is devoted to questions of dynamics; such as energy and work, impact and inertia.

Chapter IV continues the discussion of internal stresses and deformations, and extends it into the ticklish domain of the retaining wall. After elaborating the theory to what most engineers will regard as at least a sufficient extent, the author frankly admits that a "a correct theory for the design of retaining walls is as yet wanting," and that "the greatest difficulty in formulating a table of earth-thrusts arises from the fact that there is an infinite variety of earth-work."

Chapter V deals with friction and with its action in structures and in machines. Chapters VI and VII contain a further discussion of the action of beams, including an article by Professor Carus Wilson on the distribution of pressure through the section under the load. Chapter VIII deals with the strength of columns and Chapter IX with torsion. On pp. 585*a* and *b* are large figures showing the distortion of round, square and flat bars under torsional stress; but a hasty review of the text fails to discover any special reference to them. Chapter X discusses the strength of cylindrical and spherical boilers and Chapter XI the design and theory of truss bridges and of riveted joints. Chapter XII is devoted to suspension bridges and Chapter XIII to the theory of arches.

The array of examples, following the several chapters, is exceptionally complete. We notice some, however, which suggest that if the author includes them among those selected from his experience, he must have referred to the experience of the class-room.

The treatment throughout, as is now the case with most works upon these subjects, will be found rather highly mathematical by those engineers who have put some space of time between the present and their college days.

The work abounds in useful tables, among which we may note especially that on pp. 682 to 688, giving the actual weights of modern bridges and compiled from data supplied to the author by many eminent authorities. T.

Encyclopèdie Scientifique des Aide-Mèmoire publiée sous la direction de M. Léauté, Membre de l'Institut. Paris: Gauthier-Villars et fils et G. Masson. Libraires-Editeurs.

Unités et Étalons. Par Ch. Ed. Guillaume. (Broché, 2 fr. 50; cartonné 3 fr.)

Distribution de la Vapeur. Épures de Regulation. Courbes d'Indicateur. Tracè des Diagrammes. Par A. Madamet. (Br., 2 fr. 50; cart., 3 fr.)

Le Lait. Par P. Langlois. (Br., 2 fr. 50; cart., 3 fr.)

The volumes above-named are the latest issued of the interesting and valuable series of the Encyclopédie Scientifique, concerning which we have made more or less extensive references in recent impressions of the *Journal.* These volumes are worthy of quite as much commendation as their predecessors. W.

The Electric Transmission of Intelligence, and other Advanced Principles of Electricity. By Edwin J. Houston, A.M. New York: The W. J. Johnston Company, Limited, 41 Park Row. London: Whittaker & Co. 1893. 230 pp. 89 illustrations. Price, $1.

The third and concluding volume of Professor Houston's *Advanced Primers of Electricity*, is devoted to the telegraph, the telephone, electrolysis, electrometallurgy, the storage battery, electro-therapeutics, electric annunciators and alarms, electric welding, electricity in warfare and several miscellaneous applications of electricity.

The primers on multiple and cable telegraphy and telephony will be particularly appreciated by those who have had no previous knowledge of

electricity, as the author places these subjects in such a light as to make them easily understandable by any reader. The quadruplex and other systems of multiple telegraphy, as well as the principles of cable and time telegraphy need not therefore remain mysteries to the intelligent public in the future as they have in the past.

The other subjects are handled in the admirable and lucid manner that characterizes the writings of the author, whose recent election as President of the American Institute of Electrical Engineers, shows that his electrical attainments are appreciated in the higher circles of the electrical profession.

The extracts from standard authors at the end of each primer is a feature that has been highly praised in the preceding volumes, and has been retained in the present one.

Each primer is, as far as possible, complete in itself and there is no necessary connection between the several volumes of the series, of which the present one is the third and last. W.

Franklin Institute.

[*Proceedings of the stated meeting, held Wednesday, September 20, 1893.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, September 20, 1893.

JOSEPH M. WILSON, President, in the chair.

Present, 168 members and fifty-three visitors.

Additions to membership since last report, twenty-six.

Mr. W. N. Jennings exhibited an instructive series of photographs taken from a balloon, at altitudes varying from 1,000 to 6,000 feet.

Mr. A. Langstaff Johnston, of Richmond, Va., read a paper descriptive of an automatically operating safety disconnecting device for use upon electric trolley lines. The apparatus is placed in the trolley line at about every 1,000 feet, where the feed wire is tapped in. They are supported from the span wire on the end of a bracket arm. Should the trolley wire be ruptured, springs in the disconnectors on each side of the break, held in extension by the weight and tension of the wire, are released and by their contraction throw certain switches out of contact, thus cutting out the feed taps on each side of the break, which renders the affected section or block dead, but in no manner interferes with the rest of the line. The construction of the apparatus was illustrated with the aid of sectional views and its operation was practically demonstrated upon a short section of trolley line put up for the purpose in the lecture room. With the aid of an electric motor placed in the circuit the sundering of the line wire between two disconnectors was shown to cut out the section between them, while the line wire on both sides was shown to be still "live."

Mr. C. J. Hexamer exhibited a series of lantern slides of buildings and views of the World's Fair, with descriptive remarks on the same.

The meeting then proceeded to the consideration of the amendments to the by-laws of the Institute, which were presented at the stated meeting of June, 1893. (See the *Journal*, June, 1893.)

The President made a brief address explanatory of the action of the Board of Managers in recommending the proposed changes.

The proposed amendments evoked a lengthy and animated discussion, and, on being put to vote, separately, were not approved.

The Secretary presented, on behalf of Professor Rondinella, the following resolution:

That the Board of Managers be requested to consider the subject of the advisability of holding a progress exhibition during the year 1894, and to report thereon at the next stated meeting of the Institute.

The resolution was numerously seconded, and on being put to vote, was adopted.

On Mr. Heyl's motion, the following resolution was likewise adopted:

Resolved, That the Committee on Science and the Arts be authorized to award the Elliott Cresson Medal for such discoveries, inventions or manufactures, as in their opinion shall deserve it, subject to the general regulations on investigations and the following special rules:

(1) Upon the adoption, by the Committee on Science and the Arts, of a report setting forth that an invention or improvement is worthy of an award of the Elliott Cresson Medal, publication shall be made three times in the *Journal of the Franklin Institute*, stating that at the expiration of three months from the date of the first publication, the applicant will be entitled to receive the award of the said medal, unless within that time satisfactory evidence shall have been submitted to the Committee on Science and the Arts of the want of originality of the supposed invention or improvement.

(2) All applications for the Elliott Cresson Medal must be made to the Secretary of the Institute, by whom the applications and accompanying descriptions, drawings, etc., shall be laid before the Committee on Science and the Arts, and by whom all publications ordered by said committee in relation to said medal, shall be made.

On motion of the same member, the meeting voted to repeal the resolution of the Institute of May 17, 1849, defining the manner of awarding the Elliott Cresson Medal.

Adjourned.

WM. H. WAHL, *Secretary*.

PENNSYLVANIA STATE WEATHER SERVICE,

UNDER THE DIRECTION OF THE FRANKLIN INSTITUTE,

CO-OPERATING WITH THE

UNITED STATES DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.

H. L. Ball, Weather Bureau, Observer in Charge.

MONTHLY WEATHER REVIEW.

For August, 1893.

Hall of the Franklin Institute,
Philadelphia, August 31, 1893.

GENERAL REVIEW.

The most notable features of the month's weather were the drouth of the first two decades and the hurricanes on the 23d and 28th.

Of the temperature, no more need be said than that it was normal, considering the State as a whole, and that neither extremes of heat nor cold occurred. The greater part of the month gave fair and pleasant weather.

The rainfall during the first two decades was very light, and that which fell was badly distributed. Drouth, in its most serious form, existed. In the sections, of which Tioga in the north and Bedford in the south were the centres, no appreciable rainfall was received. In those sections it is said that during more than two months the ground had not been thoroughly wet. Over the whole State, rivers, springs and wells were low and the ground parched and hard. Crops of all kinds suffered severely and their yield materially shortened. Heavy local showers on the 6th brought relief, as well as destruction, to portions of Chester, Lancaster and York Counties. On that date a terrible hail-storm passed over a part of York County, destroying all crops in its path. [A full account of this storm will be found in the notes of the York observer, printed elsewhere.] The long prevailing drouth was partially relieved in Eastern Pennsylvania by heavy showers on the 19th and 20th, and the heavy rains on the night of the 23d. The hurricane of

the 23d was of great severity but was confined almost entirely to the south-eastern counties. While Bucks, Lehigh and neighboring counties received from five to eight inches of rainfall from the rains of the 19th, 20th and 23d, the counties west of the mountains had less than one-fourth of an inch. The path of the second hurricane, that of the 28th, lay through the central portion of the State, and the accompanying rains terminated the drouth in all sections.

The high winds accompanying and following both of these hurricanes completely prostrated most of the standing crops and blew off great quantities of fruit.

Though the average rainfall was slightly above the normal, the distribution was very uneven. The counties along the Delaware and Lehigh, especially Bucks County, received far more rain than elsewhere, the excess over the normal at some stations being nearly four inches. From Philadelphia westward, and including all the southern and southwestern counties, the rainfall was below the normal. In the other sections about the usual amount was received.

At Philadelphia the total deficiency in rainfall for the month was 2·41, at York 0·64, Harrisburg 1·16, Pittsburgh 0·46, and at Erie an *excess* of 0·28 inch.

From January 1, 1893, to August 31, 1893, the deficiency in temperature was, at Philadelphia 260°, York 399°, Pittsburgh 378°, and at Erie 367°.

For the same period the deficiency in precipitation was, at Philadelphia 3·32, York 4·60, Harrisburg 7·01 inches, and at Pittsburgh and Erie an *excess* of 1·76 and 3·97 inches, respectively.

EXCESSIVE PRECIPITATION.

[*One inch in one hour, or two and one-half inches in twenty-four hours.*]

Stations.	Amount. (Inches and Hundredths.)	Time.		Date.
		h.	m.	
Blooming Grove,	3·11	16	30	23d 11 p. m. to 24th 3.30 p. m.
Blue Knob,	3·15	24	—	29th
Carlisle,	2·50	24	—	29th
Doylestown,	2·98	24	—	20th
Doylestown,	3·28	24	—	24th
Forks of Neshaminy,	3·26	24	—	24th
Hamburg,	3·40	24	—	19th
Kilmer,	4·00	21	15	28th 7.30 a. m. to 4.45 a. m. 29th.
Meadville,	3·04	24	—	28th to 29th.
Outsville,	3·12	24	—	20th
Point Pleasant,	3·36	24	—	20th
Point Pleasant,	2·71	24	—	24th
Pottstown,	1·35	1	15	20th
Quakertown,	4·75	5	50	19th 7 p. m. to 11 p. m. 2·93 in. 20th 8.10 a. m. to 11 a. m. 1·80 in.
Quakertown,	2·58	7	—	23d 8.50 p. m. to "early a. m." 24th.
Seisholtzville,	2·79	24	—	20th
Skippack,	2·67	24	—	19th to 20th.
Smethport,	2·50	23	30	28th 9 p. m. to 29th 8.30 a. m.
Smith's Corner,	3·33	24	—	20th
Uniontown,	2·63	24	—	28th to 29th.

	Mean Temperature.	Mean Precipitation. Inches.
August 1888,	69°·5	7·05
1889,	67°·4	3·24
1890,	68°·4	5·76
1891,	69°·7	5·09
1892,	71°·3	3·77
1893,	70°·2	4·50

TEMPERATURE.

The mean temperature for August, 1893, was 70°·2, which is just the normal, and 1°·1 below the corresponding month of 1892.

The mean of the daily maximum and minimum temperatures, 82°·7 and 58°·1, gives a monthly mean of 70°·4, with an average daily range of 24°·6.

Highest monthly mean, 76°·0 at Philadelphia. [Weather Bureau.]

Lowest monthly mean, 63°·2 at Wellsboro.

Highest temperature recorded during the month, 99° on the 11th at Lock Haven, and on the 18th and 25th at Huntingdon.

Lowest temperature, 30° on the 14th at State College.

Greatest local monthly range, 62° at State College.

Least local monthly range, 35° at Philadelphia. [Weather Bureau.]

Greatest daily range, 50° at Saegertown on the 3d, Ligonier 15th, Huntingdon 16th, and State College on the 26th.

Least daily range, 2° at Salem Corners [Hamlinton] on the 24th.

BAROMETER.

The mean pressure for the month, 29·99, is about ·01 inch above the normal. At the United States Weather Bureau Stations, the highest observed was 30·25 at Erie on the 31st, and the lowest 29·38 at Harrisburg on the 29th.

PRECIPITATION.

The average rainfall, 4·50 inches for the month, is an excess of over one-fourth of an inch.

The largest monthly totals in inches were Doylestown, 9·99; Point Pleasant, 9·71; Quakertown, 8·90, and Smith's Corner, 8·63 inches.

The least were Immel Reservoir (Lycippus), 1·68; Ligonier, 2·19; Lock No. 4, 2·42; and Philadelphia [Weather Bureau], 2·43 inches.

WIND AND WEATHER.

The prevailing direction of wind was from the Northwest.

Average number: rainy days, 8; clear days, 14; fair days, 10; cloudy days, 7.

MISCELLANEOUS PHENOMENA.

Thunder-storms.—Blue Knob, 6th, 11th, 19th, 27th; Hollidaysburg, 6th, 11th; Wysox, 27; Le Roy, 25th, 27th; Quakertown, 19th; State College, 19th, 26th; Coatesville, 6th, 17th, 20th; Kennett Square, 6th, 17th, 20th;

Grampian, 29th; Lock Haven, 6th, 12th, 19th, 24th, 27th, 28th; Meadville, 4th, 5th, 11th, 16th, 18th; Carlisle, 6th, 12th, 19th, 29th; Harrisburg, 6th, 12th, 19th; Huntington, 19th; Kilmer, 6th, 19th, 20th; Lancaster, 6th, 17th, 24th; Lebanon, 6th, 19th; Coopersburg, 17th, 19th, 20th; Drifton, 7th, 18th, 19th, 21st 24th, 29th; Wilkes-Barre, 12th, 17th, 19th, 24th, 29th; Smethport, 1st, 6th, 18th; Pottstown, 6th, 19th, 20th; Skippack, 5th, 20th; Easton, 6th, 12th, 17th, 19th; Aqueduct, 26th; *Philadelphia*, 6th, 12th, 17th, 20th; Centennial Avenue, 6th, 12th, 17th, 20th; Blooming Grove, 6th, 19th; Girardville, 19th; Selins Grove, 6th, 12th, 24th; Somerset, 23d, 26th; Dyberry, 6th, 17th, 19th, 20th; Salem Corners, 5th, 6th, 19th; South Eaton, 6th, 19th, 20th, 27th; York, 12th; Chambersburg, 6th, 28th; Wellsboro, 8th, 19th, 27th; Phœnixville, 6th; Johnstown, 6th, 26th; Emporium, 6th, 18th, 19th, 25th, 27th.

Hail.—Quakertown, 19th; Carlisle, 6th; Lancaster, 17th; York, 6th; Chambersburg, 6th.

Frost.—Blue Knob, 30th; Smethport, 14th; Blooming Grove, 15th; Somerset, 15th; Dyberry, 14th; Wellsboro, 14th, 15th, 16th, 31st.

Coronæ.—Blue Knob, 24th; Wilkes-Barre, 7th; Dyberry, 4th.

Aurora.—Le Roy, 6th, 12th; Quakertown, 6th; Aqueduct, 6th, 8th; Selins Grove, 6th, 31st.

Solar Halo.—Le Roy, 31st; Philadelphia, 14th; Centennial Avenue, 3d, 11th, 14th; Dyberry, 4th.

Lunar Rainbow.—Wilkes-Barre, 27th.

OCTOBER WEATHER,

From United States Weather Bureau Records.

The following data, compiled from the records of observations taken during the length of time given at each station, show the average and extreme conditions during that time, and also the range within which weather variations may be expected to keep in any future October.

	Philadelphia. (22 years.)	Pittsburgh. (22 years.)	Erie. (20 years.)
Mean or normal,	56°	54°	52°
Warmest October, Average,	1879 62°	1881 60°	1879 60°
Coldest October, Average,	1876 51°	1876 49°	1889 46°
Highest temperature recorded, Date,	87° 3d, 1879; 1st, 1881	91° 3d, 1884	85° 7th, 1879
Lowest temperature recorded. Date,	31° 30th, 1873; 16th, 1876	20° 31st, 1887	26° 26th, 31st, 1887
Average date of first "killing" frost,	28th	21st	15th
Average precipitation (inches),	2·80	2·37	4·08
Average number of days with ·01 inch or more,	10	11	16
Greatest monthly precipitation, Date,	6·52 1877	6·21 1873	8·17 1885
Least monthly precipitation, Date,	0·30 1892	0·06 1874	1·18 1879
Greatest amount in 24 hours, Date,	3·70 25th, 26th, 1872	2·96 20th, 1873	2·06 23d, 1878
Greatest amount snowfall in 24 hours, Date,	0 0	trace. 31st, 1885	·5 inch. 21st, 1887
Average number clear days, Partly cloudy, Cloudy,	12 10 9	8 12 11	7 9 15
Prevailing direction of wind,	N. W.	N. W.	S.
Highest velocity, miles per hour, Date,	75 23d, 1878	40 23d, 1887	48 24th, 1887

COUNTY.	STATION.	Elevation above Sea Level (feet).	BAROMETER REDUCED TO SEA LEVEL.			TEMPERATURE.								
							MAXIMUM.		MINIMUM.					
			Mean.	Highest.	Lowest.	Mean.	Highest.	Date.	Lowest.	Date.	Mean of Maximum.	Mean of Minimum.	Mean.	Greatest.
Allegheny,	Pittsburgh, A,	890	30·00	30·22	29·57	71·0	92	9, 25	50	30	82·5	60·4	22·1	33
Berks,	Hamburg,	380	. . .	. . .	. . .	73·5	98	9, 11	49	31	86·8	60·2	26·6	40
Berks,	Reading, A,	280	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Blair,	Altoona, B,	1,181	. . .	. . .	. . .	73·3	93	12	51	15	83·4	63·2	20·2	27
Blair,	Blue Knob, A,	2,500	. . .	. . .	. . .	68·6	88	11	51	7	76·9	60·4	16·5	26
Blair,	Hollidaysburg[1] (21 days),	947	. . .	. . .	. . .	70·6	98	11	39	14	85·7	51·5	34·2	48
Bradford,	Wysox[1],	718	30·01	30·25	29·31	68·1	95	11	38	14	81·2	53·9	27·3	42
Bradford,	Le Roy,	1,400	. . .	. . .	. . .	68·3	96	11	47	14	78·2	58·3	19·7	30
Bucks,	Forks of Neshaminy[1] (29 days),	304	. . .	. . .	. . .	72·9	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Bucks,	Quakertown,[1]	536	30·00	30·46	29·61	70·8	98	12	48	31	86·0	58·7	27·3	41
Cambria,	Johnstown, A,	1,184	. . .	. . .	. . .	70·4	96	20	41	15	85·6	55·3	30·3	46
Cameron,	Emporium, A,	1,050	30·03	30·35	29·37	67·4	91	11	41	15	81·3	54·1	27·2	42
Carbon,	E. Mauch Chunk,	550	. . .	. . .	. . .	70·4	95	9	46	31	83·2	57·5	25·7	40
Centre,	State College[2]—													
	Agricultural Experiment Station,	1,191	. . .	. . .	. . .	68·5	92	11	30	14	80·8	46·2	34·6	50
Chester,	West Chester,[1]	455	29·97	30·20	29·40	72·5	91	25	54	14	82·7	64·1	18·6	30
Chester,	Coatesville,[1]	380	. . .	. . .	. . .	72·0	94	25	48	14	85·4	60·3	25·1	38
Chester	Kennett Square, A,[2]	275	. . .	. . .	. . .	70·3	80	25	60	31	. . .	. . .	. . .	. . .
Chester,	Phœnixville, A,	190	29·99	30·25	29·44	74·6	94	12	52	31	84·9	64·2	20·7	34
Chester,	Westtown,	350	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Clearfield,	Grampian,[*1]	1,450	. . .	. . .	. . .	67·6	92	11	48	30	79·7	58·2	21·5	36
Clinton,	Lock Haven,[1]	560	. . .	. . .	. . .	69·7	99	11	42	14, 15	87·0	54·9	32·1	49
Columbia,	Bloomsburg, A—													
	State Normal School,	500	. . .	. . .	. . .	71·8	97	21	49	31	83·2	60·3	22·9	31
Crawford,	Meadville—													
	Divinity Hall,[1]	1,200	. . .	. . .	. . .	66·0	89	11	43	3, 31	79·4	53·6	25·8	40
Crawford,	Saegertown, A,	1,200	. . .	. . .	. . .	66·1	94	20, 11	38	3	81·6	50·7	30·9	50
Cumberland,	Carlisle,[1]	480	. . .	. . .	. . .	70·8	95	11, 25	48	15	85·7	59·8	25·9	41
Dauphin,	Harrisburg, A,	361	29·98	30·22	29·38	73·0	95	5	54	14	83·0	63·0	20·0	31
Delaware,	Swarthmore, A—													
	Swarthmore College,	190	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Erie,	Edinboro,[*1]	1,400	. . .	. . .	. . .	66·6	86	10, 11	44	30	. . .	. . .	. . .	. . .
Erie,	Erie, A,	681	29·99	30·25	29·67	68·0	88	10	50	30	76·0	61·0	15·0	21
Fayette,	Uniontown,[1]	1,000	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Franklin,	Chambersburg,[3]	618	. . .	. . .	. . .	73·2	95	26	49	15	84·4	60·2	22·3	34
Fulton,	McConnellsburg,[1]	875	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Huntingdon,	Huntingdon, A—													
	The National College,	650	. . .	. . .	. . .	70·3	99	18, 25	43	15	86·9	53·8	33·1	50
Indiana,	Indiana—													
	State Normal School,	1,350	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Juniata,	Kilmer,[3]	475	. . .	. . .	. . .	74·9	97	11, 27	60	25, 31	. . .	. . .	. . .	. . .
Lancaster,	Lancaster, A (24 days)—													
	Franklin and Marshall College,	413	30·02	30·28	29·77	73·7	96	1	50	1	86·2	61·2	25·0	31
Lawrence,	New Castle,[1]	932	. . .	. . .	. . .	68·8	92	25	39	31	83·3	50·4	32·9	45
Lebanon,	Lebanon, A,	458	29·97	30·20	29·39	71·4	96	9	48	31	. . .	. . .	. . .	. . .
Lehigh,	Coopersburg,[1]	520	. . .	. . .	. . .	71·5	90	9, 11	53	31	81·0	62·8	18·2	25
Luzerne,	Drifton (27 days), A,	1,683	29·98	30·16	29·81	67·4	92	11	42	31	79·8	55·1	24·7	41
Luzerne,	Wilkes-Barre, A,	575	. . .	. . .	. . .	71·3	97	10, 11	44	14	85·2	57·5	27·7	41
McKean,	Smethport, A (30 days),	1,500	. . .	. . .	. . .	65·1	91	11	37	14	73·3	51·0	22·3	34
Montgomery,	Pottstown,	150	. . .	. . .	. . .	74·8	95	12	52	14	86·0	63·7	22·3	32
Montgomery,	Skippack, A,	. . .	. . .	. . .	. . .	72·8	93	12	47	14	84·8	60·8	24·0	41
Northampton,	Easton—													
	Lafayette College,	325	. . .	. . .	. . .	72·5	93	12	50	30	82·0	63·0	19·0	31
Perry,	(Aqueduct) Logania,[*1]	367	. . .	. . .	. . .	73·2	97	27	47	15	. . .	. . .	. . .	. . .
Philadelphia,	U. S. Weather Bureau, A,	117	29·98	30·22	29·47	76·0	93	9	58	14	84·8	66·5	18·3	31
Philadelphia,	1529 Centennial Avenue, A,	. . .	29·98	30·22	29·47	75·2	93	25	56	14	84·4	66·1	18·3	27
Philadelphia,	3911 Locust Street, A,	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Pike,	Blooming Grove,[*1]	. . .	. . .	. . .	. . .	67·2	91	9, 10	32	14	. . .	. . .	. . .	. . .
Schuylkill,	Girardville[3],	1,000	29·94	30·19	29·68	69·2	90	9, 10	49	14, 31	80·5	58·6	21·9	31
Snyder,	Selins Grove, A,	455	30·04	30·34	29·71	73·8	97	9	42	15	87·7	50·9	27·8	41
Somerset,	Somerset,[1]	2,250	. . .	. . .	. . .	70·2	96	25, 28	42	8, 21	84·3	56·1	28·2	41
Tioga,	Wellsboro,[*1]	1,327	. . .	. . .	. . .	63·2	90	11	34	14	. . .	. . .	. . .	. . .
Union,	Lewisburg, A,	450	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Warren,	Columbus,	1,410	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Wayne,	Dyberry,[1]	1,100	. . .	. . .	. . .	66·1	93	10, 11	35	14	80·9	52·1	28·8	41
Wayne,	Honesdale,[1]	1,000	. . .	. . .	. . .	66·5	87	27	42	14	77·6	55·5	22·1	31
Wayne,	(Salem Corners) Hamlinton,[1]	1,600	. . .	. . .	. . .	66·9	92	10	47	14	78·6	58·4	20·2	31
Westmoreland,	(Immel Reservoir) Lycippus,[*1]	1,490	. . .	. . .	. . .	68·1	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Westmoreland,	Ligonier (30 days),	1,750	. . .	. . .	. . .	67·9	95	27	37	15	84·7	51·7	31·0	51
Wyoming,	South Eaton, A,	660	. . .	. . .	. . .	68·0	90	10, 11	45	14	78·7	57·2	21·5	31
York,	York, A,	385	29·95	30·17	29·36	72·1	95	25	47	14	84·7	59·3	25·4	37
	JULY, 1893.													
	Report received too late for July Bulletin.													
	Lancaster (18 days),	. . .	29·99	30·21	29·80	73·3	91	9, 18	53	10, 11	84·5	62·2	22·3	31

A, Observations taken at 8 A. M. and 8 P. M. B, Observations taken at 12 Noon. * Extremes from dry thermometers [1] Mean temperatures, 7 + 2 + 9 + 9

OF THE PENNSYLVANIA STATE WEATHER SERVICE FOR AUGUST, 1893.

Daily Range.				Relative Humidity.	Dew Point.	Precipitation.				Number of Days.			Wind.			Observers.
Greatest.	Date.	Least.	Date.			Total Inches.	Total Snowfall During Month.	Depth of Snow on Ground at End of Month.	Number of Days Rainfall.	Clear.	Fair.	Cloudy.	Prevailing Direction. 7 A. M.	2 P. M.	9 P. M.	
33	9, 15	9	6, 28	65·1	57·8	2·94	. . .	. . .	7	15	12	4	NE	. . .	N	O. D. Stewart, Weather Bureau.
40	16	10	29	. . .	. . .	5·74	. . .	. . .	5	16	7	8	NW	SE	NW	William Shipe.
. . .	. . .	. . .	. . .	. . .	. . .	3·25	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	Franklin Yager.
27	10	12	1	. . .	. . .	2·92	. . .	. . .	8	. . .	. . .	. . .	. . .	. . .	. . .	Dr. C. B. Dudley
26	9	8	29	. . .	. . .	3·58	. . .	. . .	4	9	18	4	NW	NW	NW	A. H. Boyle.
48	9	21	12	. . .	. . .	4·18	. . .	. . .	5	12	5	4	NW	W	NW	Prof. J. A. Stewart.
43	10	10	29	79·8	61·8	5·43	. . .	. . .	14	14	3	14	NW	NW	NW	Charles Beecher.
30	11	8	29	. . .	. . .	5·92	. . .	. . .	13	12	14	5	SW	SW	SW	G. W. T. Warburton
. . .	. . .	. . .	. . .	. . .	. . .	6·93	. . .	. . .	10	15	9	5	N	N	W	J. C. Hilsman.
43	11	11	20	75·3	62·3	8·90	. . .	. . .	9	11	16	4	NE	NW	NE	J. G. Heacock.
48	15	12	28	. . .	. . .	2·90	. . .	. . .	9	15	10	6	S	. . .	S	E. C. Lorentz.
43	15, 16	12	29	88·0	59·5	3·00	. . .	. . .	9	10	15	6	NW	. . .	W	T. B. Lloyd.
40	9	8	29	. . .	. . .	4·45	. . .	. . .	4	14	12	5	W	W	W	F. C. Wintermute.
50	26	18	1	70·8	58·0	3·14	. . .	. . .	7	12	14	5	W	W	W	Prof. Wm. Frear.
30	6	8	28	68·0	61·0	3·65	. . .	. . .	9	22	2	6	N	NW	SE	J. C. Green, D.D.S.
38	16	12	28	. . .	. . .	4·68	. . .	. . .	8	19	8	4	W	W	W	W. T. Gordon.
. . .	. . .	. . .	. . .	. . .	. . .	3·74	. . .	. . .	9	14	13	4	N	. . .	NW	B. F. Kirk.
34	16	7	14	69·3	62·2	3·61	. . .	. . .	8	13	9	9	NW	. . .	NW	Knowles Croskey.
. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	Harry Alger.
38	16	10	29	. . .	. . .	3·26	. . .	. . .	8	10	15	6	SW	W	SW	Nathan Moore.
49	15	12	29	. . .	. . .	2·82	. . .	. . .	7	19	7	5	W	W	W	Prof. J. A. Robb
37	16	11	24, 29	. . .	. . .	3·07	. . .	. . .	6	10	9	12	E	. . .	E	Prof. J. G. Cope.
40	3	14	12	. . .	. . .	7·03	. . .	. . .	9	6	19	6	N	S	W	Chas. Graves.
50	3	10	17	. . .	. . .	5·20	. . .	. . .	11	16	11	4	NW	. . .	NW	J. G. Apple.
40	15	6	28	. . .	. . .	5·82	. . .	. . .	7	11	12	8	W	SW	W	J. E. Pague.
31	5	7	28	68·0	60·0	3·69	. . .	. . .	9	13	8	10	E	E	E	F. Ridgway, Weather Bureau.
. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	Prof. Susan J. Cunningham.
. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	C. F. Sweet.
21	13	5	29	65·0	56·0	3·61	. . .	. . .	8	8	18	5	NE	. . .	NE	P. Wood, Weather Bureau.
. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	Wm. Hunt.
34	16	10	29	. . .	. . .	2·61	. . .	. . .	3	21	5	5	NW	NW	NW	G. W. Ludwig.
. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	T. F. Sloan.
50	16	13	29	. . .	. . .	3·49	. . .	. . .	4	24	2	5	W	. . .	W	Prof. W. J. Swigart.
. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	Prof. S. C. Schmucker
. . .	. . .	. . .	. . .	. . .	. . .	5·19	. . .	. . .	8	9	18	4	W	W	W	R. J. Mickey.
37	9	10	28	68·3	60·9	3·77	. . .	. . .	5	11	9	4	W	. . .	W	W. E. Bushong
45	7	14	29	. . .	. . .	3·37	. . .	. . .	7	17	10	4	SW	SW	SE	Wm. T. Butz.
. . .	. . .	. . .	. . .	76·3	62·4	5·30	. . .	. . .	7	16	10	5	NE	. . .	NW	G. W. Hayes, C.E.
29	16	7	29	. . .	. . .	6·29	. . .	. . .	8	17	9	5	NE	NW	NE	Dr. M. H. Boye
43	11	9	19, 29	72·0	59·0	6·65	. . .	. . .	7	14	8	5	. . .	. . .	. . .	J. R. Wagner.
44	16, 17	3	30	. . .	. . .	3·76	. . .	. . .	5	21	7	3	W	. . .	W	A. W. Betterly.
44	15	9	29	. . .	. . .	4·15	. . .	. . .	9	10	15	5	SW	. . .	SW	Armstrong & Brownell
34	11, 16	10	28	71·0	63·0	4·52	. . .	. . .	6	22	5	4	W	W	W	Charles Moore, D.D.S
41	14	6	20	. . .	. . .	5·76	. . .	. . .	8	19	2	10	W	. . .	W	B. W. Dambly.
28	7	4	2	. . .	. . .	5·89	. . .	. . .	6	15	10	6	. . .	. . .	. . .	J. W. Moore.
. . .	. . .	. . .	. . .	. . .	. . .	3·78	. . .	. . .	11	15	9	7	N	N	N	Richard Callin.
29	6	10	28	68·0	61·0	2·43	. . .	. . .	9	10	12	9	N	N	N	L. M. Dey, Weather Bureau.
25	6	9	28	70·9	62·0	3·90	. . .	. . .	10	13	12	6	N	. . .	SW	John Comly.
. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	Ralph L. Paddock.
. . .	. . .	. . .	. . .	. . .	. . .	5·35	. . .	. . .	6	. . .	. . .	. . .	. . .	. . .	. . .	John Grathwohl.
36	16	9	28	. . .	. . .	4·11	. . .	. . .	8	16	10	5	NW	NW	W	E. C. Wagner.
44	15	14	31	. . .	. . .	4·07	. . .	. . .	7	1	21	9	SW	. . .	SW	J. M. Boyer.
41	15	13	29	. . .	. . .	3·93	. . .	. . .	6	13	12	6	NW	NW	NW	W. M. Schrock.
. . .	. . .	. . .	. . .	. . .	. . .	4·59	. . .	. . .	10	13	8	10	N	N	N	H. D. Deming
. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	Prof. W. G. Owens.
. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	Wm. Loveland.
44	16	8	24	. . .	. . .	4·45	. . .	. . .	5	. . .	. . .	. . .	NW	W	NW	Theodore Day.
34	14	6	24	. . .	. . .	3·17	. . .	. . .	9	. . .	. . .	. . .	. . .	. . .	. . .	John Torrey.
35	9	2	24	. . .	. . .	5·19	. . .	. . .	10	11	9	11	NW	W	NW	T. B. Orchard, M.D.
. . .	. . .	. . .	. . .	. . .	. . .	1·68	. . .	. . .	4	. . .	. . .	. . .	. . .	. . .	. . .	Murray Forbes
30	15	7	29	. . .	. . .	2·19	. . .	. . .	5	23	4	3	. . .	. . .	. . .	J. T. Ambrose
35	16	8	24	. . .	. . .	5·41	. . .	. . .	9	19	4	8	SW	. . .	SW	B. M. Hall.
38	16	11	29	80·8	64·8	3·40	. . .	. . .	6	18	7	6	NW	. . .	NW	Mrs. L. H. Grenewald.
34	10	11	1	76·4	65·4	1·23	. . .	. . .	6	7	9	9	SE	. . .	SW	

† 9 + 4. ‡ Mean of 8 + 8 + 2. § Mean of 7 + 7 + 2. Absence of numerals indicates that mean of temperature is from maximum and minimum readings. † 25 days.

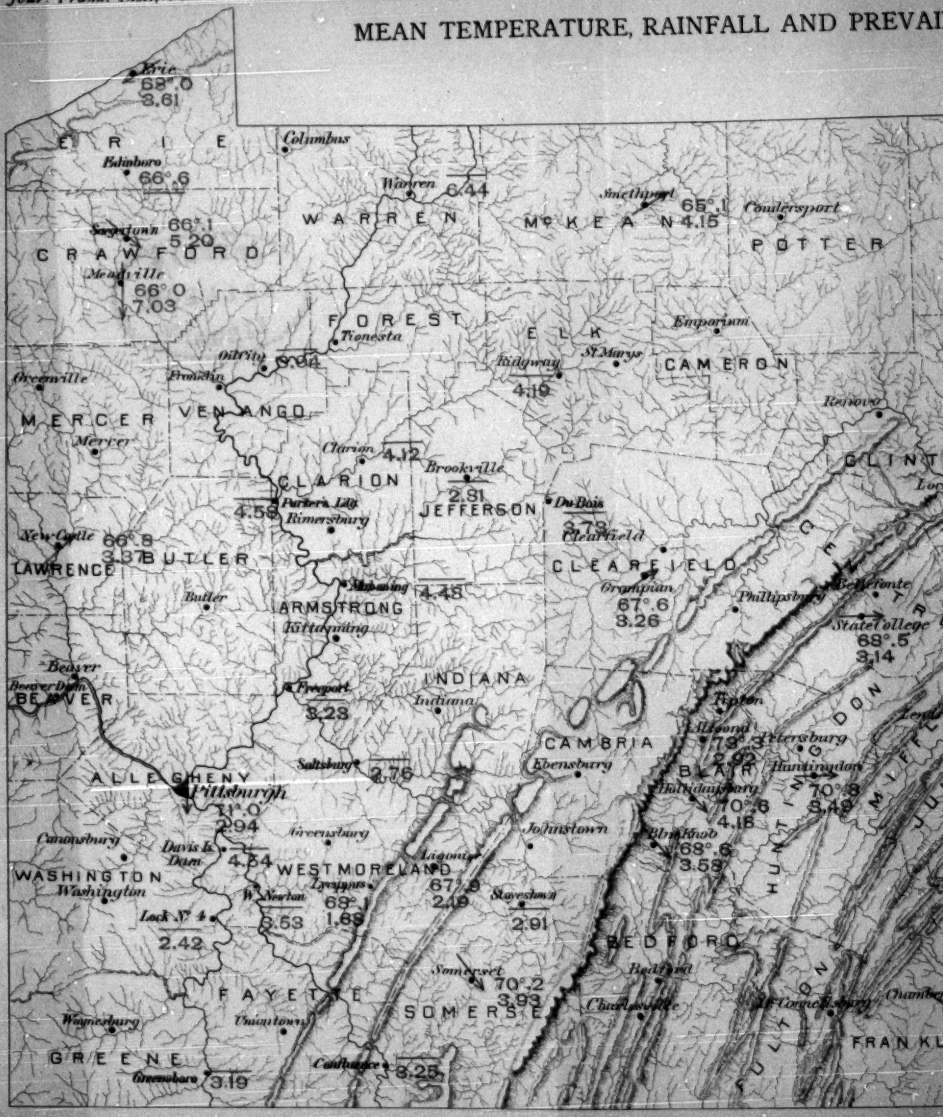
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total.
Delaware Basin.																																
Blooming Grove,					.19												.98			.44				3.11	.07				1.33			5.35
Browers Lock,	.06				.12	.43											.05			.99				1.62					.69			3.96
Coatesville,				.04		.93						.08					.20			1.12			.03	1.24					1.04			4.68
Coopersburg,					.01	.01						.03					.36		.72	2.26			.03	1.90					.90			6.22
Doylestown,					.04	.09						.90					.64			2.98				3.28					2.13			9.99
Dyberry,																	.69		.08				.40	1.88					1.40			4.45
Easton,						.02						.01					.34			2.08				2.11					.73			5.09
Forks of Neshaminy,	.14				.19	.06						.05				.08	.33			1.38			.08	3.26					1.36			6.93
Frederick,	.09					.06											.05			1.81				1.72					.74			4.46
Hamburg,												.33					.08		3.40					1.13					.80			5.74
Honesdale,						.03						.03					.40		.12	.01			.08	1.79	.05				.73			3.17
Kennett Square,	.02				.08	.50						.21					.25	.02		.80				1.35					.51			3.74
Lansdale,				.12								.03				.07	.08		1.90					2.12					1.00			5.32
Mauch Chunk,																	.31			1.22				1.31					1.61			4.45
Ottsville,	.51				.36							.01	.01				.10			3.12				2.10					1.05			7.46
Philadelphia, a†	.15				.12	.07						.02					.07			.08			.05	1.32					.55			2.43
Philadelphia, b,	.08				.13	.36						.19					.08	.01		.07			.06	2.20					.74			3.90
Philadelphia, c,																																
Phœnixville,					.06	.18	.01					.01					.07			1.12				1.59					.57			3.61
Point Pleasant,	.47				.07							.21					.40		.07	3.36				2.71					2.42			9.71
Pottstown,						.04											.06		1.04	1.35				1.28					.75			4.52
Quakertown,	.05				.07							.23					.46		2.95	1.80			.01	2.58					.75			8.90
Reading,				.01	.01	.01						.01					.10		.03	1.26				1.28					.64			3.25
Salem Corners,					.01	.02							.04				.40			.55	.02			2.00	.28	.10			2.06			5.42
Seisholtzville,												.12					.38		.04	2.79				2.07					1.04			6.44
Skippack,	.10				.08	.02											.07		.85	1.74				2.00					.98			5.76
Smith's Corner,	.41	.05										.08					.41			3.83				2.45					2.00			8.63
Swarthmore,																																
West Chester,	.02				.08	.77						.02					.08			.84			.12	1.16					.56			3.65
Westtown,																																
Susquehanna Basin.																																
Altoona,						.03						.03	.07							.03				.23			.08		2.40	.05		2.92
Aqueduct,						.04						.10					.08	.01	.25	.52			.15	.65		.03		.55	1.40			3.78
Bloomsburg,												.44						.02	.08	.22				1.37					.94			3.07
Blue Knob,						.04																		1.15			.13		1.15			3.58
Carlisle,						.64						.01	.10							1.47			.20	.50					2.90			4.82
Drifton,						*	.14						*				.09	.80	1.01	*	.89			1.71			*		2.01			6.65
Emporium,						.06						.09					.30		.17					.34	.06		.30	.12	1.36			3.00
Girardville,						.06						.02					.04		.72					.54	.86			.60	1.27			4.11
Grampian,						.54					.18						.15							.98	.03		.23	.17	1.68			3.76
Harrisburg,†						.35						.13	.01				.05		.40	.93			.06	.54					1.22			3.69
Hollidaysburg,												.21			*	*	*	*	*	*	*	*		*	.52	.05		1.00	2.40			4.18
Huntingdon,						.06						.40								.40													3.49
Kilmer,						.02					.05	*	*	*	*	*	.14			.10	.16			.72				1.20	2.80			5.19
Lancaster,					.01	.37											.24							1.72					1.23			3.77
Lebanon,						.09						.08					.05		1.33	1.07				1.76					.99			5.30
Le Roy,	.02					.17						.46					.50	.15	.05	.06	.23			1.08	.30		.85	.05	2.00			5.92
Lewisburg,																																
Lock Haven,						.33						.23					.12		.06					.63			.19		1.06			2.82
Selins Grove,						.09						.55							.10	.09				.59			.45		2.30			4.07
South Eaton,						.07						.45					.34		.18	1.43	.15			1.86			.24		.69			5.41
State College,						.24					.27	.22					.07		.03					.21	.21	.08	.15	1.60			3.14
Wellsboro,						.04					.05	.35					.26	.10	.24	.05				1.25			.40		1.85			4.59
Wilkes-Barre,												.25					.38		.22					1.69					1.08			3.70
Wysox,					.07	.00						.61				.15	.03	.07	.06	.24			.83	.81	.90		.59	1.70	.05			5.43
York,						1.03						.50					.07		*	.14				.65					1.01			3.40

†U. S. Weather Bureau Stations. *Missing.

URING AUGUST, 1893.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total.
Ohio Basin.																																
Beaver Dam,	.31			.35	.02	.16						.13	.04				.17		.25							.20	.04	.40	.30	2.51	.40		4.98
Brookville,						.47						.28	.08				.09		.03				.41				.04	.23	.89			2.81
Clarion,						.05						.13	.03				.24		.06							.08	.06	.07	2.80			4.12
Columbus,																																
Confluence,	1.18			.02								.12					.16						.03	.14		.01	.02	1.47	.20		3.25
Davis Island Dam,	.86			.25	.68	.05						.09					.14		.10							.01	.08	2.25	.03		4.54
DuBois,						.65											.03	.08	.18					.32	.16	.52	.20	.04	1.65			3.73
Freeport,	.02			.05		.24											.07		.09							.09		.21	2.53	.03		3.23
Greensboro,	.92			.01								.11	.08				.52												1.48	.07		3.19
Immel Reservoir,												.18				.23	.13												1.14			1.68
Indiana,																																
Johnstown,						.06						.02				.01	.04							.25		.19	.08	.45	1.16			2.20
Ligonier,												.08					.13	.27										1.70	.11			2.19
Lock No. 4,													.09				.15												1.84	.14		2.42
Mahoning,	.03					.35						.35	.03				.19		.40							.12	.05	.34	2.62			4.48
Meadville,				.25		.60					1.44	.39				.14	.22	.55										.40	3.04			7.03
New Castle,						.24						.35				.30		.15	.25								.15		1.93			3.37
Oil City,						.23						.21	.13						.03								.03		2.37			3.04
Parker's Landing,						.28	.01					.06	.04				.13		.10							.10	.06	.04	3.75	.01		4.58
Pittsburg,†				.26								.25				.01	.23	.06										.57	1.66			2.94
Ridgway,					.32											.20		.17					.36	.20		.07	.30	1.77				4.19
Saegertown,					.06	.14					.69	.97				.07	.06	.14	.11								.01	.04	2.31			5.00
Saltsburg,	.40					.29							.22				.14												1.70	.02		2.76
Smethport,	.20			.a		.30						.15					.40		.20					.30			.05	.05	2.50			4.15
Somerset,												.40										.15			.15		.43		1.60	1.20			3.93
Stoyestown,	.31															.30			.14							.12	.27	.09	.49	.93	.17		2.91
Uniontown,																																
Warren,	.50				.18	.28						.41	.42														.03		3.18			6.44
West Newton,	1.12			.03									.08				.17												1.67	.46		3.53
Potomac Basin.																																
Chambersburg,						.08						.62																	1.91			2.61
McConnellsburg,																																
Lake Basin.																																
Erie,†						.06					.20	.36				.26	.08	.24										.46	1.95			3.61

MEAN TEMPERATURE, RAINFALL AND PREVAI

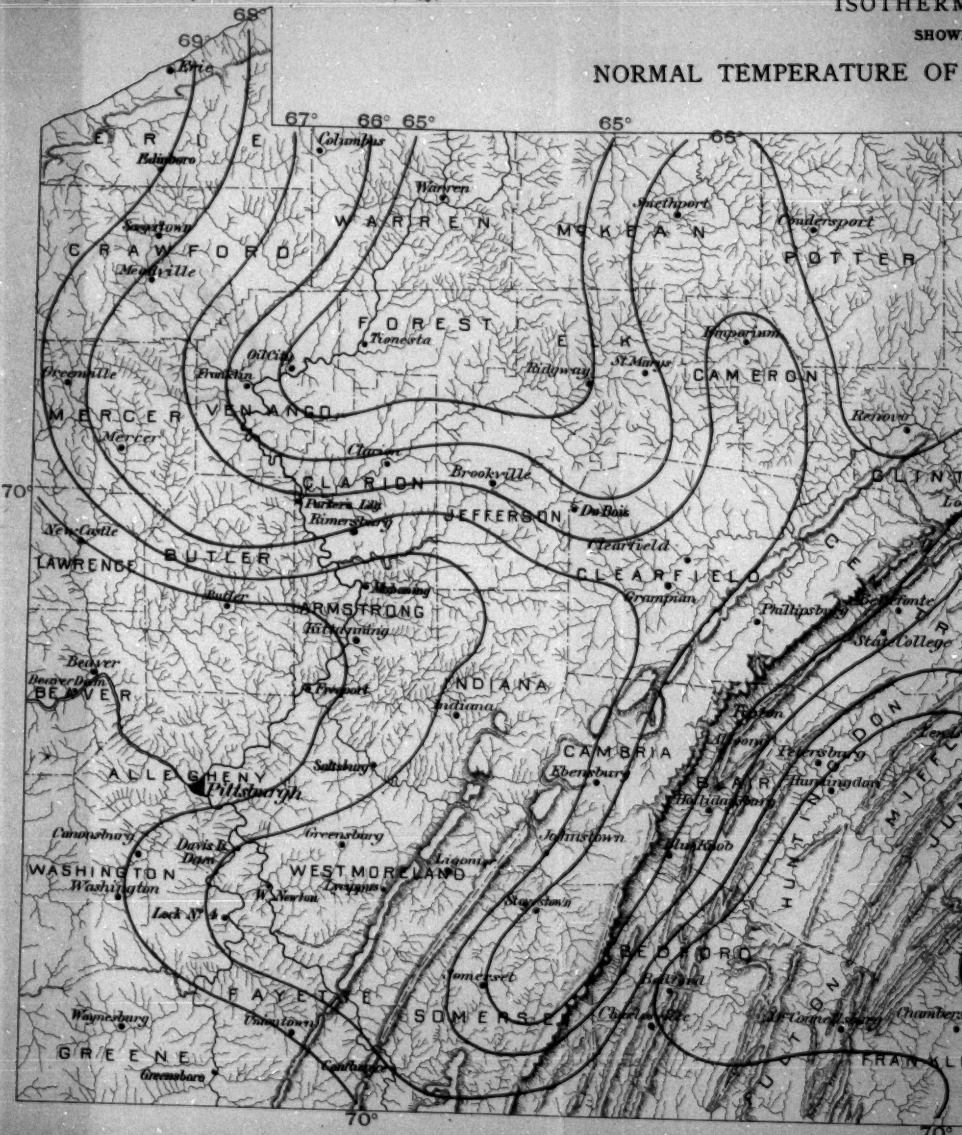


AILING WIND DIRECTION FOR AUGUST. 1893

ISOTHERM

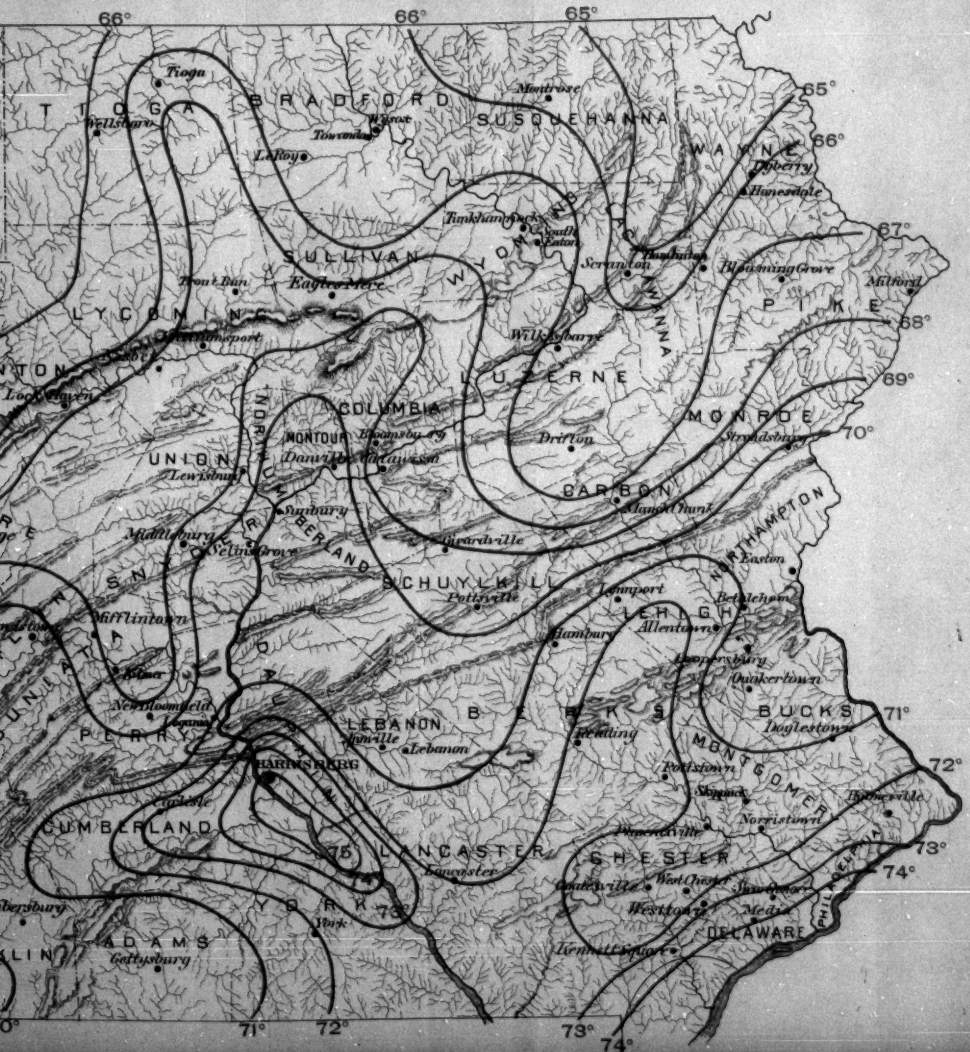
SHOW

NORMAL TEMPERATURE OF



RMAL LINES,

OWING THE

F PENNSYLVANIA FOR AUGUST.

State Weather Service.